Metals & Mining

COPPER TOP PROJECTS 2022

A Deficit on the Horizon

With the 10th iteration of our Copper Top Projects report, we analyze the Top 50 projects that are set to form >60% of new copper supply in the next five years and account for c.US$100 bn of capex. We highlight key takeaways from our analysis:

1) Increased incentive price to bring new projects online, with an average incentive price of US$9k/t, up c.30% vs 2018, and a marginal incentive price of US$13k/t to solve an 8mn t deficit by the end of this decade given cost inflation, rising required returns and widespread project delays.

2) Material deceleration in supply growth after 2023: New copper supply from approved projects peaks in 2024E, after which there are no significant copper projects on the horizon until 2027/28. While supply growth appears muted from 2024, demand is likely to accelerate given the push towards a low-carbon economy and growing green copper demand.

3) New project approval process slows: About 50% of the projects analyzed in both our 2018 and 2022 editions have seen their production start year delayed by an average of three years.

4) In our global coverage, we find that over a 5Y horizon, Zijin Mining, CMOC, First Quantum, Teck Resources and Anglo and Oz Minerals hold some of the strongest growth projects**. Looking beyond 2026, SCCO and BHP** stand out for growth project pipelines that should allow them to offset reserve depletion and grade declines. **Rio Tinto, Antofagasta, Lundin Mining and MMG** also benefit from large-scale projects that are likely to substantially increase their production and CFs.

The Goldman Sachs Group, Inc.

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Copper in numbers

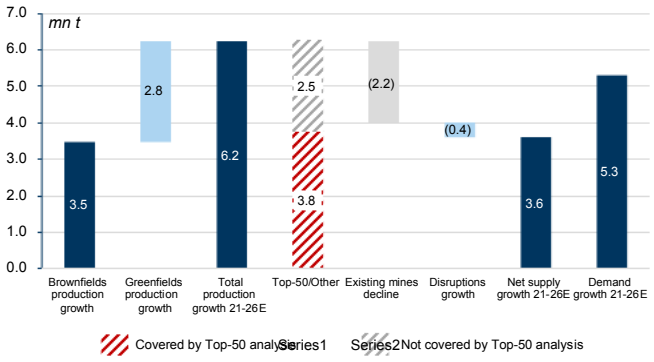
Exhibit 1: Key takeaways

Source: Goldman Sachs Global Investment Research

The GS Supply Demand model for copper is a collaboration between our Equity and Commodities analysts. The views expressed outside this analysis are those of the Equity analysts, with the exception of the chapter titled 'Structural demand story intact despite cyclical headwinds', which was contributed by our Commodities analysts, and the chapter titled 'ESG concerns lead to a slowing project approval process and supply disruptions', which was co-authored with our GS SUSTAIN team. All authors listed on this report are Equity analysts, with the exception of Nicholas Snowdon, Jeffrey Currie, Aditi Rai and Annalisa Schiavon, who are Commodities analysts, and Evan Tylenda, who is an analyst in our GS SUSTAIN team.

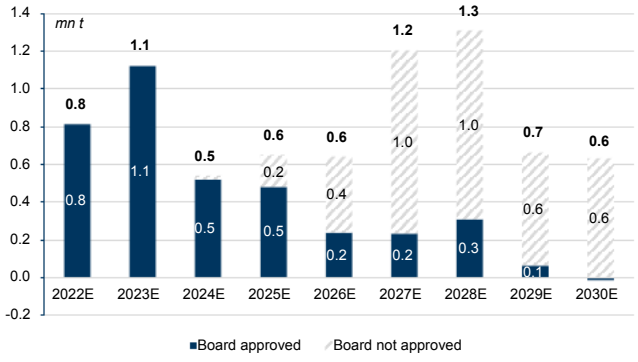
Top Projects in 18 charts

Exhibit 2: We analyze the largest 50 copper projects, which are likely to bring c.4mn t of additional copper supply by 2026
Demand and supply growth 2021-26E, mn t



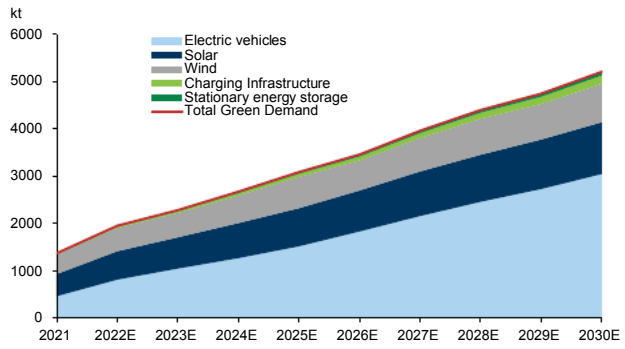
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 3: Most of this incremental supply is likely to come online in the next 2Y, after which supply growth decelerates until 2027/28
Top-50 projects copper production growth 2022-2030E



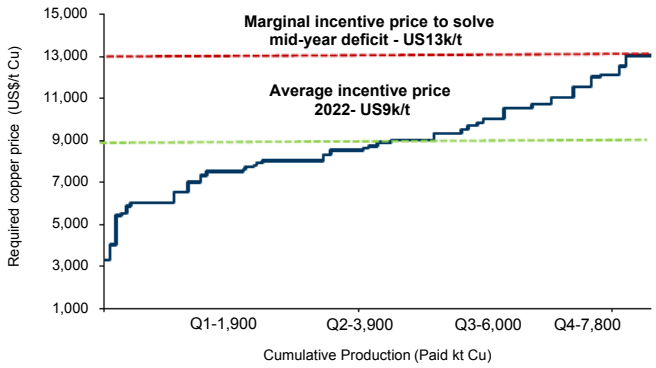
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 4: Demand grows in the second half of the decade on the back of decarbonization and green trends, as per our global commodities team



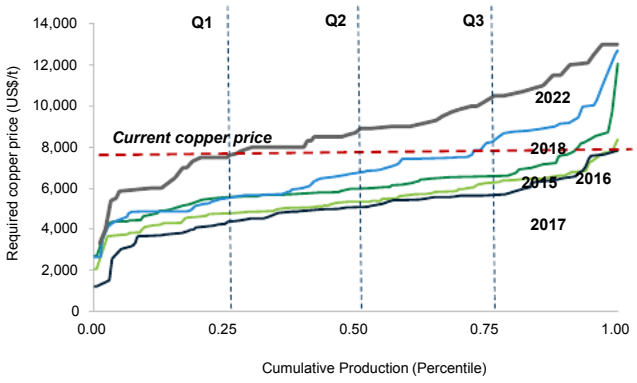
Source: Goldman Sachs Global Investment Research

Exhibit 5: We find an avg incentive price of c.$9k/t, with a marginal incentive price of $13k to solve the deficit by the end of this decade
Cost curve 2022 (incl. sunk costs)



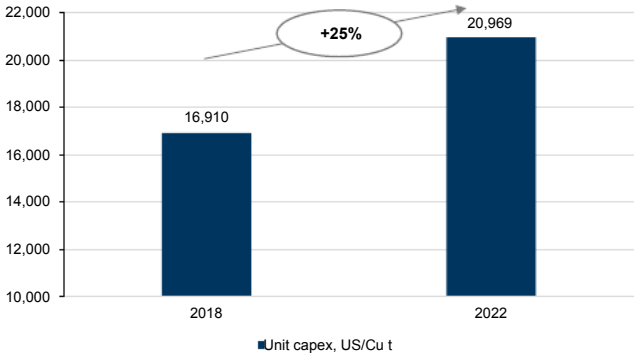
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 6: Incentive price to bring new projects online has increased significantly, by c.30% vs 2018
Cost curve 2022 vs previous years



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 7: This is driven by significant capex inflation...
Unit capex, US$/Cu t



Source: Company data, Goldman Sachs Global Investment Research

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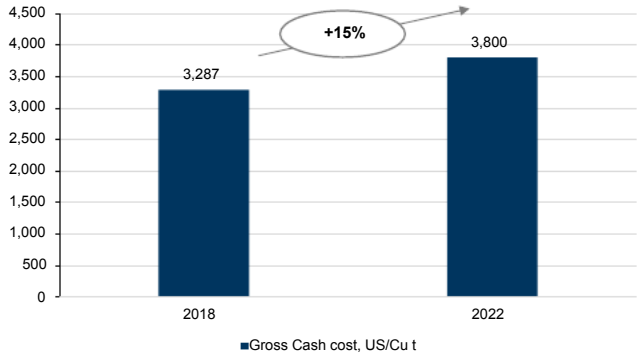

Source: Company data, Goldman Sachs Global Investment Research

Exhibit 9: ...and project delays
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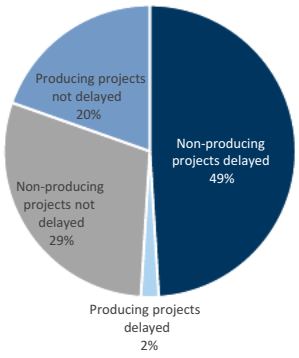

Source: Company data, Goldman Sachs Global Investment Research

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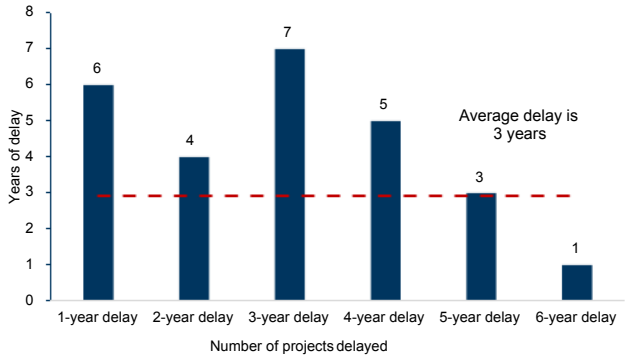

Source: Company data, Goldman Sachs Global Investment Research

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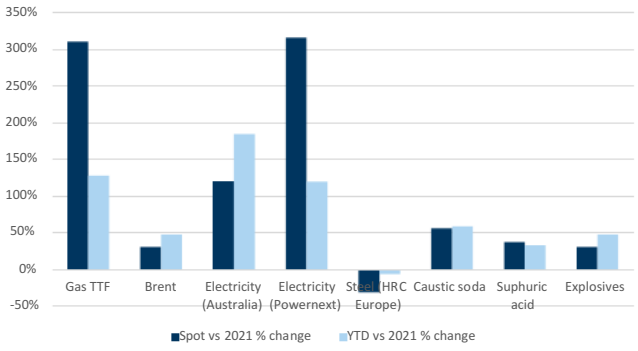

Source: Bloomberg, Goldman Sachs Global Investment Research

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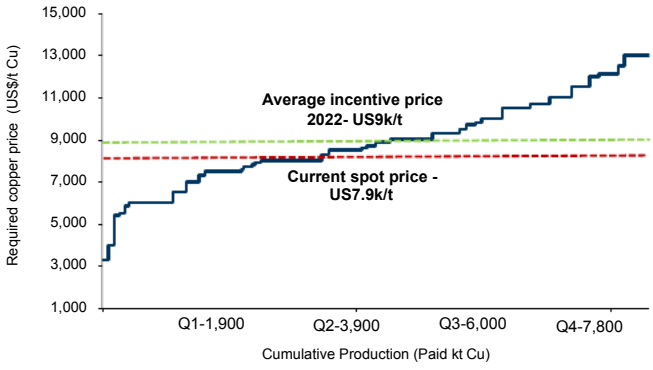

Source: Company data, Goldman Sachs Global Investment Research

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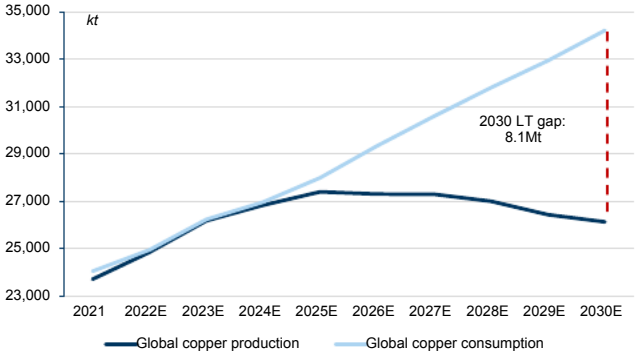

Source: Woodmac, Goldman Sachs Global Investment Research

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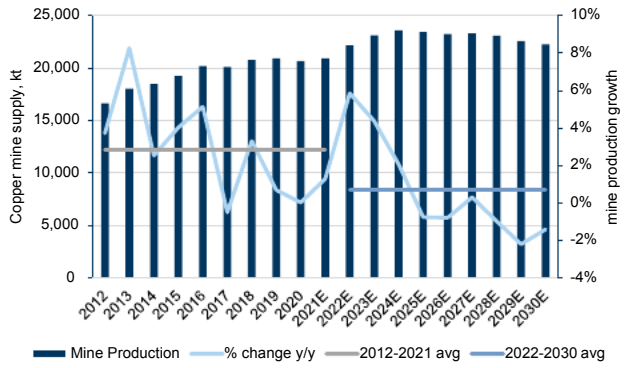

Source: Goldman Sachs Global Investment Research

Exhibit 15: Growth capex in real terms is c.40% lower in 2022-26E than in 2010-21

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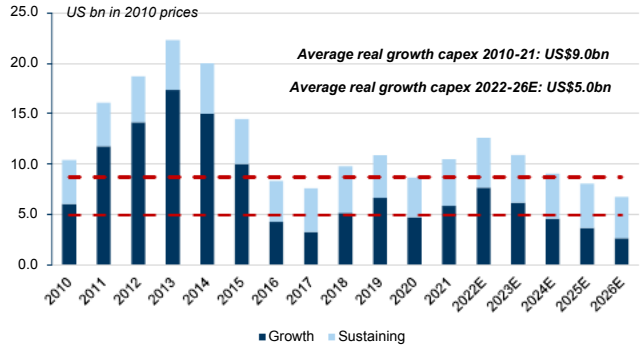
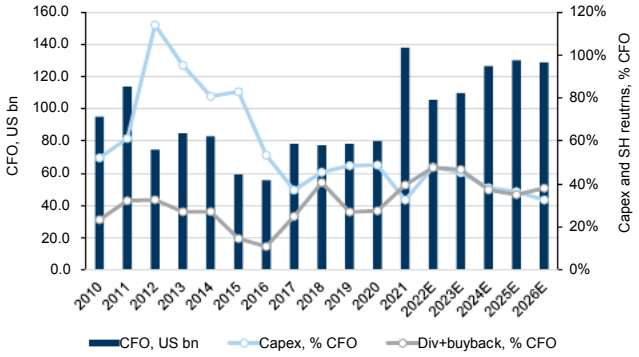


Source: Company data, Goldman Sachs Global Investment Research

Exhibit 16: Despite decade-high cash flows, companies are focusing on shareholder returns rather than increasing capex

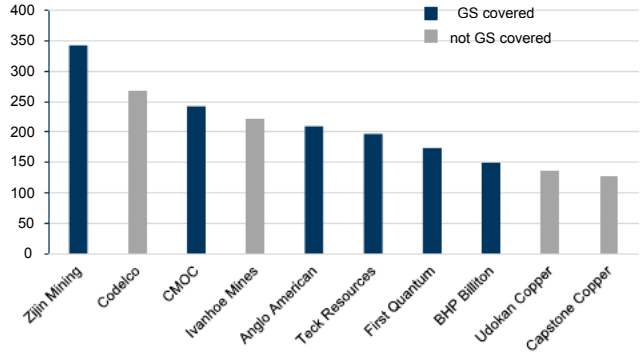
CFO, capex and shareholder returns



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 17: Zijin Mining, China Moly and Anglo in our global coverage account for the highest volume growth to 2026E...

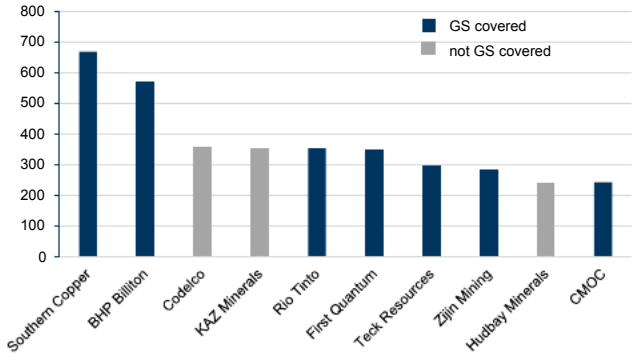
Extra copper supply from analyzed copper projects 2021-2026E by company, kt



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 18: ...while Southern Copper, BHP, Rio Tinto and First Quantum hold longer-term cu production projects

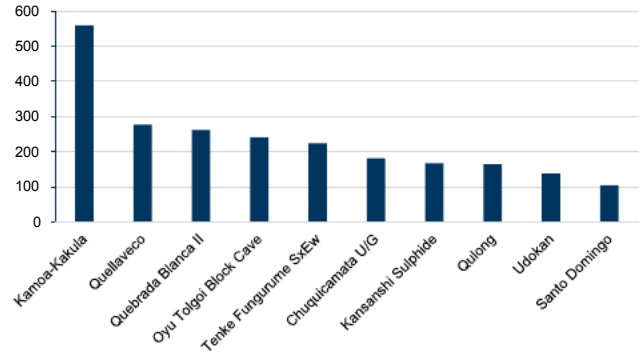
Extra copper supply from analyzed copper projects 2021-2030E by company, kt



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 19: Kamoa-Kakula, Quellaveco and QB-2, the 3 largest projects, bring c.1,000 kt by 2026E

Extra copper supply 2021-26E, kt



Source: Company data, Goldman Sachs Global Investment Research

PM Summary

In this year's edition of Copper Top Projects, we focus largely on supply in our analysis of the copper market. With the near-term demand story unclear as a result of a host of factors (China Covid response, global recession fears), we step outside the 6-12 month range and take a 48-60 month view on the drivers of supply and their implications. This by no means ignores the demand side of the copper story. However, we believe we can provide the most value to investors through a detailed supply picture which can then be complemented with a demand view. In arriving at our final conclusions, we use our commodities team's demand forecasts.

Key takeaways from our copper supply-side work

- **We expect major supply additions in 2022/23, followed by a considerable slowdown until 2027/28.** We note that the majority of supply additions in 2027/28 come from unapproved projects, **implying risks of delayed project starts and supply additions shifting to after 2030** given project complexity and scrutiny on ESG: **50% of projects were delayed by an avg. of 3Y vs 2018**.
- We estimate **miners need to spend an aggregate c.$150bn of capex** over the next decade to solve the expected deficit of 8 mn t. However, amid an investor preference for SH returns, miners are **holding back on capex**; we estimate next 5Y **growth capex** to be **40% lower vs 2010-21** in real terms.
- We note that given the inflationary pressures, the **required copper price for projects has increased significantly** (c.30% higher vs 2018), and unit capex is up 25% vs 2018.
- Across the analyzed 50 projects, we find that the **average incentive price is c.US$9k/t**. **The marginal incentive price to solve the deficit by the end of this decade** and incentivize 8 mn t of new supply **is US$13k/t**. **Under spot pricing, c.60% of projects are not economically viable including sunk costs and c.40% excluding sunk costs.** This, in our view, could disincentivize/delay decisions on new investment projects, thus exacerbating the deficit in the second half of the decade forecast by our commodities team.
- **c.50% of additional supply from the top-50 projects comes from outside conventional jurisdictions**, including markets such as DRC, PNG, Botswana, Panama, Zambia and Mongolia given higher reserve grades; this leads to higher returns/copper prices being required and indicates possible delays in project sanctioning/execution.

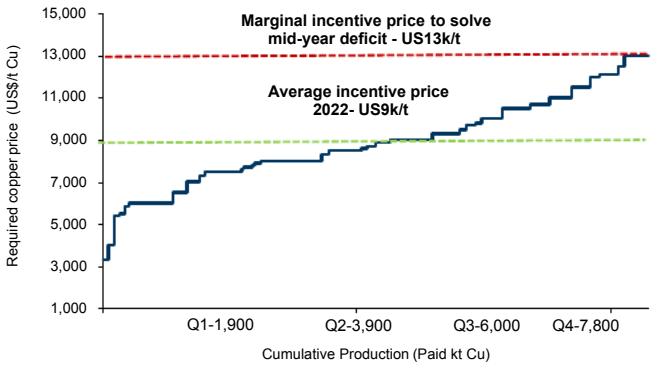
- **In our global coverage, we find that over a 5Y horizon, Zijin Mining, CMOC, First Quantum, Teck Resources, Anglo American and Oz Minerals** hold some of the strongest growth projects that are highly profitable and could materially lift their future cash flows and production. Looking at **growth optionality beyond 2026, Southern Copper and BHP** stand out for growth project pipelines that should help offset copper reserve depletion and grade declines. **Rio Tinto, Antofagasta, Lundin Mining and MMG** also benefit from large-scale projects that are likely to substantially increase their production and CFs. BHP, ANTO and RIO have the highest usage of seawater, making the water permitting process easier.

Average incentive prices rise by 30% on higher capex/opex inflation and required returns

We see the average copper incentive price increasing to US$9k/t for 2022, up c.30% versus 2018. This is largely driven by higher costs, as well as higher required rates of return for some jurisdictions given tax and political uncertainty. Inflation is having a severe impact on companies' costs (see our cost inflation note), and we estimate c.25% unit capex and c.15% unit opex inflation in our 2022 Top Projects versus 2018.

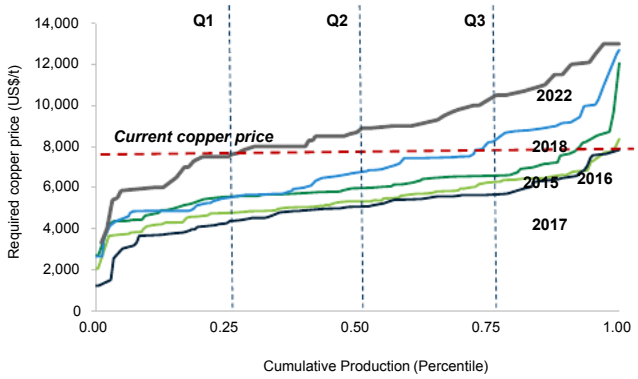
Marginal incentive price to solve deficits is $13k. We find that the marginal incentive price is c.US$13k/t to solve the deficit by the end of this decade and add 8 mn t of new supply (part of which will replace existing mines, resulting in c.4 mn t new supply additions). This is consistent with our global Commodities team's view that longer-term prices have to climb significantly higher to incentivize new supply.

Exhibit 20: Across the analyzed 50 projects, we find that the average incentive price is c.$9k/t, with a $13k marginal incentive price to solve deficits
Cost curve 2022 (incl. sunk costs)



Source: Company data, Goldman Sachs Global Investment Research

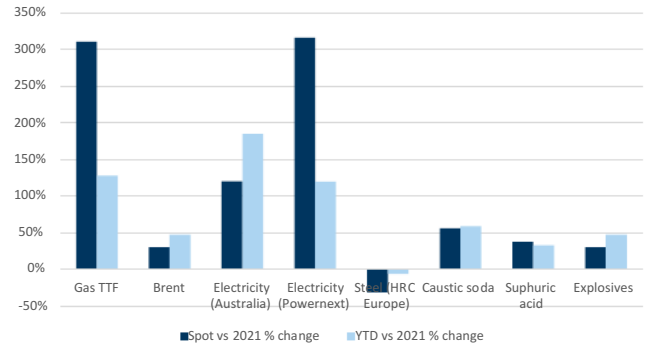
Exhibit 21: Incentive price to bring new projects online has increased significantly, by c.30% vs 2018
Cost curve 2022 vs previous years



Source: Company data, Goldman Sachs Global Investment Research

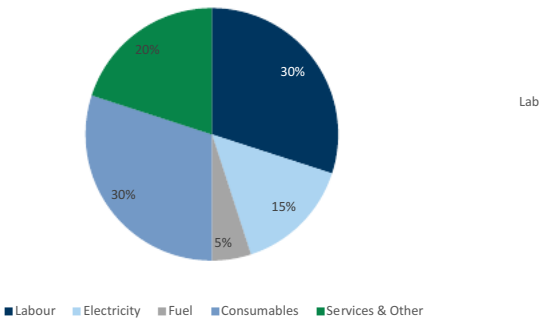
Cost inflation remains top of mind for global miners. Cost inflation is having a severe impact on miners' P&Ls, primarily driven by higher prices for energy and consumables, resulting in higher operating costs and capex (see our recent cost inflation note here). Upward cost revisions have become common in our global mining coverage, and we expect more to come later in the year, with potential spillover effects into 2023. Across the board, companies have flagged opex inflation on the back of higher energy and consumables prices, and capex inflation driven by higher cement and energy prices, as well as higher logistics costs. Longer lead times flagged by several companies also imply longer construction periods.

Exhibit 22: 2022 has seen significant cost inflation, driven by higher input prices
Raw material price changes - spot and YTD versus 2021 avg



Source: Bloomberg, Goldman Sachs Global Investment Research

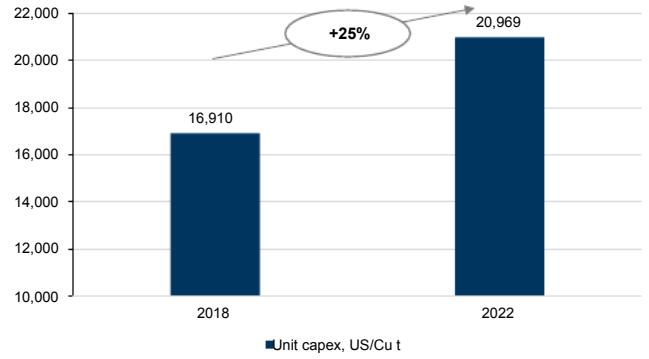
Exhibit 23: Labour, electricity and fuel account for approximately half of mining costs
Estimated mine costs based on Wood Mackenzie and company data, 2021



Source: Wood Mackenzie, Company data, Goldman Sachs Global Investment Research

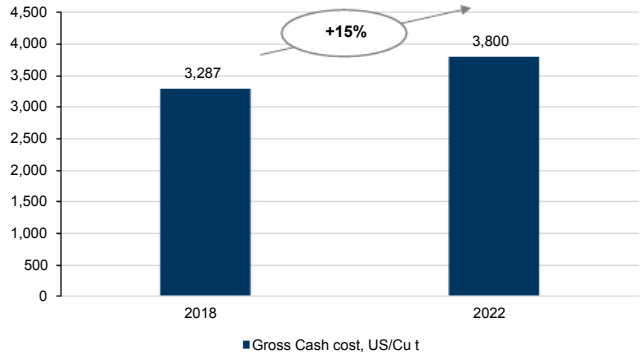
We estimate c.25% unit capex and c.15% unit opex inflation in our 2022 Top Projects versus 2018. For 25 out of 50 projects in the 2022 Top Projects that are yet to be launched, companies have announced upward capex revisions averaging 30%. For projects where technical reports have not been updated for the last 1-3 years, we inflate last reported capex numbers by 25% on average to account for higher input costs.

Exhibit 24: We see c.25% unit capex inflation in 2022 vs 2018...
Unit capex, US$/Cu t



Source: Company data, Goldman Sachs Global Investment Research

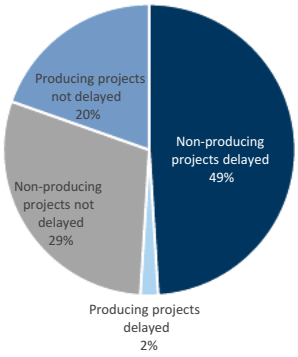
Exhibit 25: ...and c.15% unit opex inflation in the 2022 Top Projects versus 2018
Gross cash cost across Life of Mine, US$/Cu t



Source: Company data, Goldman Sachs Global Investment Research

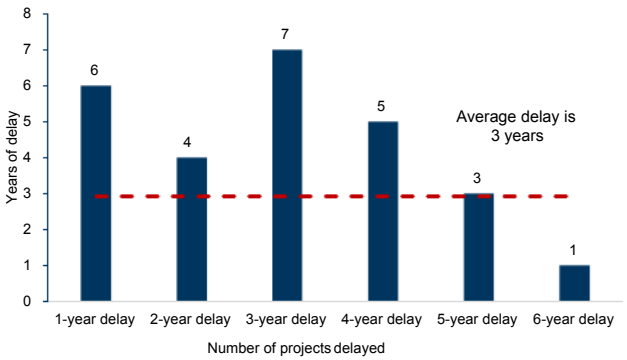
Project delays are widespread, prolonging the period to bring new supply online, and increasing incentive prices. About 50% of the projects analyzed in both our 2018 and 2022 editions have seen their production start year delayed by an average of three years. This, in our view, is caused by a slowing approval process as a result of a) increasing jurisdictional risks, b) ESG concerns among communities and governments, and c) investor caution on expansion capex.

Exhibit 26: About 50% of the projects analyzed in both our 2018 & 2022 editions have seen their production start year delayed...
Breakdown of copper top projects that appear in both 2018 and 2022 editions



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 27: ...by an average of 3 years

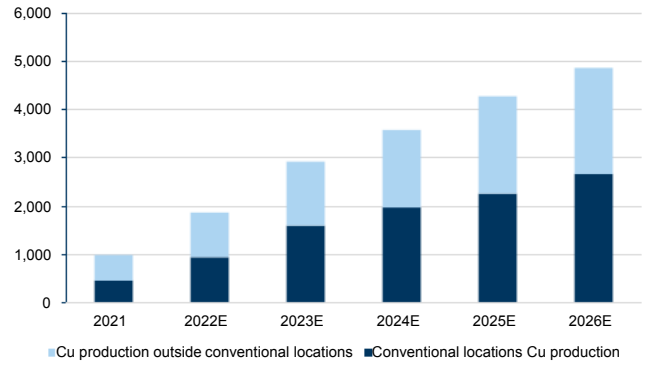


Source: Company data, Goldman Sachs Global Investment Research

Grade declines and rising fiscal uncertainties move production away from conventional jurisdictions

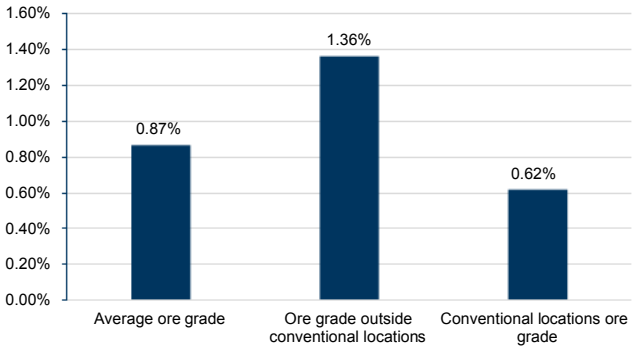
We see production moving out of conventional jurisdictions as a function of i) **grade declines** and lack of project availability in historically low-risk conventional jurisdictions, and ii) **fiscal uncertainty** forcing companies to reconsider investment (Chile, Peru).

Exhibit 28: Among our top-50 projects, c.50% of extra supply in 2021-26E is coming from outside conventional jurisdictions
kt



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 29: We can see a clear bifurcation in grades of projects in conventional vs unconventional jurisdictions

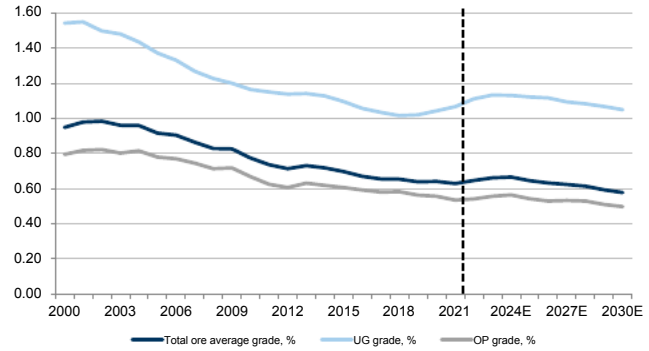


Source: Company data, Goldman Sachs Global Investment Research

Grade declines and lack of project availability

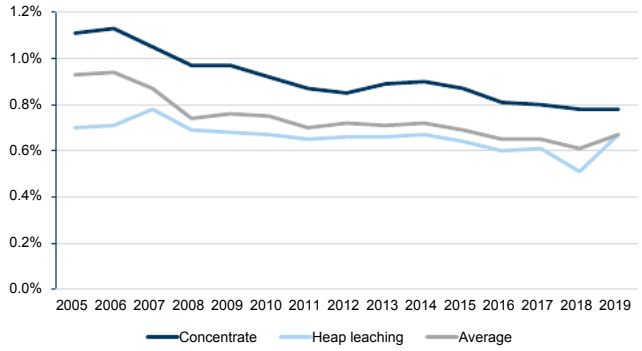
Grades have been steadily declining in the last decade given depletion of high-grade easily available reserves. Global ore reserve grades declined from 0.7% in 2000 to 0.5% in 2020. Chile, the biggest copper producer, has seen grades of ore mined decline from c.1% in 2000 to 0.7% in 2019. At the same time, fiscal uncertainty in Chile (see more below) has delayed the approval of new projects and decreased its perceived attractiveness as a mining location with low jurisdictional risk. As grades decline at conventional locations, reducing miners' profits and returns, and fiscal uncertainty increases, mining operations are increasingly moving to jurisdictions such as DRC, PNG, Botswana, Panama, Zambia and Mongolia that have high-grade untapped resources. Among our top-50 projects, c.50% of extra supply in 2021-26E is set to come from outside conventional jurisdictions.

Exhibit 30: While grades are falling globally...
Average grade of total ore mined globally, %



Source: Wood Mackenzie

Exhibit 31: ...those for projects in conventional locations like Chile are declining more rapidly
Average copper ore grade in Chile by production route, %



Source: IEA

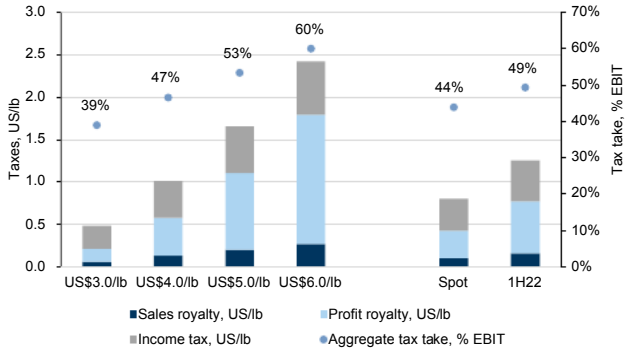
Increasing fiscal uncertainty in conventional jurisdictions: Deep dive on Chilean Royalty Proposal

Jurisdictional risks and fiscal uncertainty are increasing as rising commodity prices coupled with accelerating inflation prompt governments to consider imposing higher taxes on the mining industry and redistributing mining profits. We believe that rising fiscal uncertainty in conventional jurisdictions like Chile is raising the risk profile of previously 'low-risk' jurisdictions, leading companies to move elsewhere.

Chile — increase in tax take for miners is on its way, albeit at a more moderate level compared with previous proposals. Currently, most large copper miners in Chile pay a flat, or invariable, rate regardless of the copper price, under agreements that run until the end of 2023. The draft new constitution proposes a set of regulatory changes, including increased tax take for miners. The tiered profitability and royalty components include a royalty which can fluctuate between 1% and 7% of sales for assets with output of 200 kt or higher and 1-2% of sales for assets producing 50-200ktpa of copper. The profitability component is a variable tax rate based on EBITDA ranging between 2% and 36% depending on copper prices (the highest marginal tax rate of 36% applies if prices are above $6/lb). While the impact of the revised proposal would be smaller than that of the previous version (see our report here), if approved, at the spot copper price of $8k/t, the overall tax take (sales royalty, profit royalty, income tax) would increase from 33% to 41% of EBIT for midsized mines (50-200kt Cu output) and from 33% to c.45% for large mines (>200kt of Cu output), on our estimates.

Proposed tax system increases average incentive price for Chilean projects by 15%. 15 out of the Top 50 projects in our analysis are located in Chile, with LOM production of 1,600kt (c.22% of total output for the 55 projects). Under the existing tax system, we estimate that the average incentive price for Chilean projects is US$10k/t and the average IRR (incl. sunk costs) is 15%. Under the proposed new tax system, the average incentive price would increase by 15% to US$11.9k/t and the average IRR (incl. sunk costs) decrease to 11%.

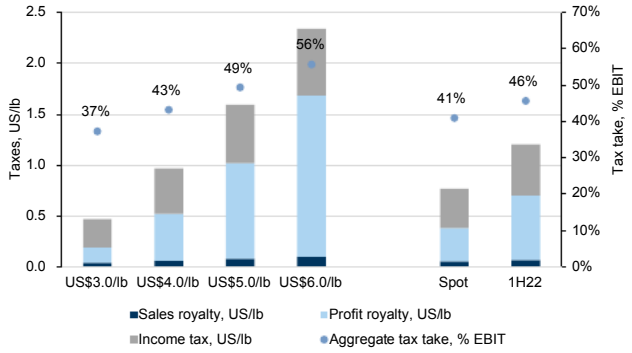
Exhibit 32: Tax take for a >200ktpa producer under the proposed new system



Assumes production of 250ktpa, costs (incl. D&A) of US$1.7/lb and zero interest expense. Assuming profit royalty is fully deductible for income tax purposes

Source: Chile Ministry of Finance, Goldman Sachs Global Investment Research

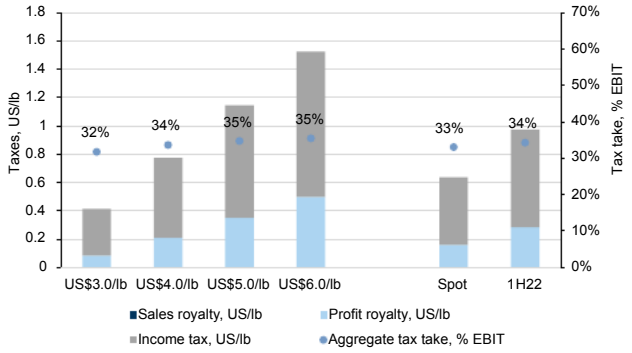
Exhibit 33: Tax take for a >50ktpa and <200ktpa producer under the proposed new system



Assumes production of 100ktpa, costs (incl. D&A) of US$1.7/lb and zero interest expense. Assuming profit royalty is fully deductible for income tax purposes

Source: Chile Ministry of Finance, Goldman Sachs Global Investment Research

Exhibit 34: Tax take for a mid/large-scale producer under current system

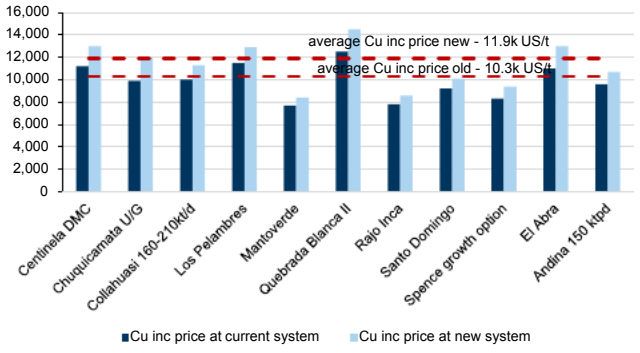


Assumes production of 250ktpa, costs (incl. D&A) of US$1.7/lb and zero interest expense. Assuming profit royalty is fully deductible for income tax purposes

Source: Chile Ministry of Finance, Goldman Sachs Global Investment Research

Exhibit 35: Proposed tax system increases average incentive price for Chilean projects by 15%

Cu incentive price for selected Cu top projects in Chile under current and proposed tax system



Source: Goldman Sachs Global Investment Research

Exhibit 36: Over 50% of foreign owned copper mines in Chile have tax stability agreements expiring in 2023
Tax stability agreements between the Chilean government and foreign-owned copper mines (excludes state-owned copper miner Codelco)

Mine	2021E copper production (kt, 100% basis)	Company	Tax Agreement expiry year	Current tax rate or tax bracket (% tax on mining profits)
Lomas Bayas	63	Glencore (100%)	N/A	5%-14%
Candelaria	170	Lundin 80%, Sumitomo 20%	2023	5%-14%
El Abra	85	Freeport 51%, Codelco 49%	2023	5%-14%
Los Bronces	339	Anglo American 50.1%, Codelco/Mitsui 29.5%, Mitsubishi 20.4%	2023	5%-14%
Collahuasi	628	Anglo American 44%, Glencore 44%, JCR 12%	2023	5%-14%
Escondida	990	BHP 57.5%, Rio Tinto 30%, Jeco Corp 10%, Jeco 2 2.5%	2023	5%-14%
Cerro Colorado	65	BHP 100%	2023	5%-14%
Los Pelambres	345	Antofagasta 60%, Nippon 25%, MM LP 15%	2023	4% 2014-2017, 5%-14% 2018-2023
Zaldivar	101	Antofagasta 50%, Barrick 50%	2023	4% 2014-2017, 5%-14% 2018-2023
Caserones		Nippon 77.4%, Mitsui 22.6%	2027	0%-5%
Quebrada Blanca 2	-	Teck 60%, SMM/SC 30%, Enami 10%	2037	5%-14%
Carmen de Andacollo	49	Teck 90%, Enami 10%	2027	5% until 2021, 5%-14% 2022-2027
Antucoya	76	Antofagasta 70%, Marubeni 30%	2030	5%-14%
Sierra Gorda		KGHM 55%, Sumitomo 45%	2030	5%-14%
Centinela	273	Antofagasta 70%, Marubeni 30%	2031	Tesoro: 4% (2014-2017), 5% (2018-2023); 5%-14% (2024-2029) Esperanza: 5% (2014-2023), 5%-14% (2024-2029) Encuentro: 5%-14% (2016-2031)
Spence	255	BHP 100%	2032	0% until 2026, 5%-14% 2027-2032

Source: Company data, Chile Mining Council, consejominero.cl, Data compiled by Goldman Sachs Global Investment Research

Chile — other proposals in new constitution concerning miners: water usage and increased environmental protection. In addition to potential tax regime changes, the draft new Chilean constitution has also focused on tackling the environmental crisis, addressing climate change, biodiversity loss and toxic pollution. The final draft submitted on July 4th includes new restrictions on mining near glaciers that could impact around 20-25% of the current annual copper production and put several expansion projects at risk. It also establishes that water is a "natural common good" that would not carry property rights for those who receive usage authorizations, which could significantly impact miners given that new institutions would now handle water management, and its access could be limited. Citizens will vote to approve or reject the draft constitution by referendum on September 4th, 2022. The latest opinion polls indicate that voters are unlikely to back the new constitution (link), implying that uncertainty over the new constitution and mining tax regime could linger well beyond the referendum in September.

Peru — second-largest copper producer; potential for an increased tax burden on miners amid local community protests. In July 2021, the new Peruvian president, Pedro Castillo, won the presidency amid pledges to rewrite the constitution and redistribute mining profits. The new government initially proposed not to grant permit extensions for some key mines given environmental concerns, and to redistribute mine profits more evenly. While the government stance towards mining subsequently softened, social unrest started in March 2022, along with demands by local communities for financial compensation and a share of future profits in mining and blockages of several key copper mines (see the following chapter). Against this backdrop, we see potential for an increasing tax burden on mining in Peru going forward.

Tax disputes and other fiscal risks outside conventional jurisdictions are widespread. As growth projects migrate outside conventional jurisdictions, they face risks of tax disputes (some potentially backward-looking) and weaker protection of property rights, as well as export bans (Indonesia) and capital controls (Argentina). Several projects in our top-50 analysis have faced delays in production start/ramp-up due to disputes with local governments over obligations to pay outstanding tax amounts not paid in previous years of production (the Tenke Fungurume project in DRC, Kansanshi expansion project in Zambia, and Oyu Tolgoi project in Mongolia).

ESG concerns lead to a slowing project approval process and supply disruptions

The following section was co-authored with our GS SUSTAIN analyst Evan Tylenda

Obtaining social and environmental licenses as part of the permitting process is becoming increasingly difficult, leading to project delays and supply disruptions

Getting to global net zero requires copper, but local ESG concerns weigh on new supply. Copper is a critical raw material for global ESG objectives such as decarbonization and electrification, but it is becoming increasingly challenging at a local level to obtain social and environmental licenses for constructing and operating new mines. Given growing wariness among environmental groups and indigenous communities of potential negative impacts of mining on water, land, biological diversity and GHG emissions, local governments are increasingly withholding/withdrawing licenses for mining operations. We believe this situation — under-investment in the old economy and local ESG concerns prompting avoidance of traditional carbon- and resource-intensive commodity production well before the transition to a decarbonized economy and global net zero — will lead to progressively larger deficits in key base metals, including copper, going into the middle of this decade.

Mining process — licensing is key to proceed with construction. Bringing new copper mines to the production stage is a long and bumpy road, consisting of several stages that can run successively or in parallel (in the case of development and licensing): exploration (geological surveys, sampling and drilling, which can typically take 1-5 years), development (scoping, pre-feasibility, feasibility studies) and licensing (2-5 years, although this can vary significantly), construction (brownfield 3-4 years, greenfield up to 6-8 years), production (depending on the reserve base, this can vary from 5 to >50 years), closure and site remediation (2-10 years). **Licensing is a crucial process for new mines that precedes the start of construction.** Depending on the jurisdiction, this process can be more or less stringent, but we observe a trend of the licensing stage becoming longer and more difficult across different geographies: **out of the 18 countries holding the Top-50 copper projects in our analysis, 10 have had recent cases of miners facing difficulties in obtaining mining licenses/having operations suspended due to breach of environmental regulations, or local community opposition preventing mining operations**; this applies to both traditional, lower-risk jurisdictions (Chile, Peru, Brazil, USA, Canada) and non-traditional jurisdictions (Papua New Guinea, DRC, Zambia).

Licensing involves receiving multiple permits that involve different stakeholders. Before construction and mining operations commence, project operators are required to prepare a comprehensive environmental and social impact assessment (ESIA) that explores the impact of mining on terrain/land use, water and air quality, fish and aquatic resources, wildlife, archaeology, socioeconomic indicators, and so on. Once submitted to the authorities, this might go through several iterations, with requests for clarification or more information before final approval. Separate ESIAs might be required to connect the project to the national grid or construct new roads and other infrastructure. After final submission and approval, the ESIA usually has to be updated and resubmitted once

every several years. A detailed mine closure plan is also required to be submitted within some time (usually a year) after ESIA approval. Once the ESIA is approved by government authorities, the company can then obtain multiple permits for mine construction and operations issued by multiple local and/or state or federal authorities and agencies: these include water licenses, land use/air emissions/waste management permits, authorization for wastewater treatment, labor permits and road construction permits. Companies need to interact with multiple stakeholders, including local authorities, government agencies, indigenous communities and labor unions to receive support and formal approval for the project. Without getting multiple stakeholders on board, licensing can become a significant bottleneck to bringing new mines online, and can lead to projects being delayed for >10 years and/or suspended (see examples below).

Local community opposition and more stringent environmental requirements are increasing hurdles for existing mines and making it more difficult to receive permissions for new projects, decreasing project values. The focus on environmental issues caused by mining will likely continue to intensify, and be reflected in taxation (such as carbon taxes) and government legislation, as well as consumer expectations. Existing concerns are largely related to resource consumption — water and electricity sources and usage, fuel consumption and land use (including mine reclamation and tailings); and emissions — pollution and greenhouse gases. Higher environmental demands regarding the safety of operations and disposal of tailings could increase the financial burden on miners, and cause disruptions to existing operations and delays to new supply coming online as the process of obtaining environmental permits becomes increasingly difficult.

Below, we highlight some examples of the impact of more stringent environmental regulation and local community opposition on mining operations.

Operating mines:

- Peru (MMG's Las Bambas mine and Southern Copper's Cuajone mine, c.470 kt aggregate 2021 production): Communities in Peru have long protested against mining operations in the country, saying that the mines pollute local water sources, and negatively impact farming without contributing enough to the community. Since social unrest started in the country in March 2022, indigenous surrounding communities have demanded financial compensation and a share of future profits at two large mines (Las Bambas, Cuajone). These protests led to the suspension of operations at the Cuajone mine in February'22 for 52 days (c.170 kt of copper production in 2021, implying c.25 kt of lost production) and at the Las Bambas mine in April'22 for >50 days (c.300 kt of copper production in 2021, implying c.40 kt of lost production).
- Chile (BHP/Rio Tinto's Escondida mine, Antofagasta's Zaldivar mine, c.1,100 kt 2021 production): In April'22, the government of Chile sued mines operated by BHP (Escondida mine), Albemarle and Antofagasta (Zaldivar mine) over alleged environmental damage caused in the northern Salar de Atacama salt flats that led to a decrease in water availability.

- Chile (Anglo American's Los Bronces and El Soldado operations, and Cerro Negro and San Cayetano mines): In May'22, the Chilean authorities rejected an environmental permit for the Los Bronces Integrated Project, which is aimed at expanding the current open pit with the underground section of a mine. Since then, the authorities have also rejected plans for investments at Anglo's El Soldado operation, as well as two smaller mines, Cerro Negro and San Cayetano.

Greenfield projects:

- PNG (Harmony Gold/Newcrest Mining's Wafi Golpu project, c.140 ktpa LOM production): A judicial review case was filed against the decision to issue an environmental permit for the project. The process of receiving environmental permits has been stalled for more than a year; a dispute is currently ongoing over the design of the mine waste disposal system.
- Peru (Southern Copper's Tia Maria project, c.120 ktpa LOM production): Protests took place in 2011, 2015 and 2019 among the local population, driven by concerns over environmental pollution and the impact on crops and water supplies. Project development has been delayed for 10+ years, and there is a lack of clarity on when the project will come online.
- USA (Hudbay Minerals' Rosemont project, c.115 ktpa LOM production): Environmental groups and indigenous communities have been engaged in 10+ years of protests given concerns over water contamination, threats to biological diversity, and the destruction of ancestral burial grounds. As a result, the company has decided to pursue an alternative two-phase mine plan to advance the Copper World project, with the first phase expected to require only state and local (not federal) permits.

Implementing best practices for every stage of mining process is becoming increasingly important to get new supply online and avoid interruptions at existing mines. Companies that plan for social and environmental requirements (health services, training programs for the local workforce, housing, security), engage local communities early and arrive at an early-stage agreement prior to a government permitting review could avoid delays in the review process. When it comes to the closure and reclamation process, best practices include establishing a reclamation fund for the clean-up work and preservation of local jobs, as well as working with local communities and authorities on subsequent land-use plans. One of the best examples is Teck Resources' Sullivan Mine closure in 2001: to mitigate the loss of US$2 mn yearly tax revenue to the municipality of Kimberley, Canada, Teck Resources worked together with local authorities to diversify the local economy by creating a solar power generation site called SunMine at the former Sullivan Mine concentrator site and a four-season resort built around golf and skiing.

Water scarcity continues to pose challenges for the miners

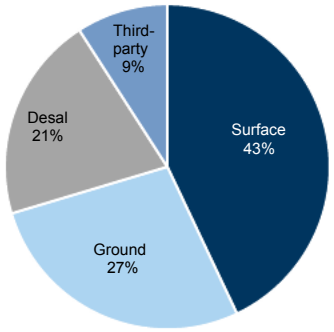
Copper mining is a water-intensive process, with c.70 cubic meters of fresh water required to produce 1t of copper. In copper production, water is used during mining (in the drilling process, for dust suppression), ore processing and grinding, during the concentrating/flotation process (c.70% of total water consumed is during flotation), and in refining/smelting (mainly for cooling).

Surface and groundwater remain the prevailing sources for copper production. Copper miners source water primarily from surface water (lakes, rivers), rainfall, stormwater and groundwater. These sources account for c.70% of water used for companies in our global coverage. Seawater and third-party sources make up c.20% and 10% of total water withdrawal, respectively. While surface water might be easily accessible and the cheapest to use, its availability can depend on weather conditions, and miners require permits to access it. Use of desalinated seawater can decrease dependency on weather conditions and remove the need to obtain permissions, but requires substantial upfront investment and several years of construction, and is more expensive operationally given electricity consumed during the desalination process.

Water permits are increasingly difficult to obtain; droughts can further reduce surface water availability. Companies obtain new water through permits, legal rights, and leases for groundwater, including rainfall or stormwater and surface water sources, such as lakes or rivers. Water security Is increasingly recognized by mining companies as a principal risk, influencing not only their ability to extract and produce copper, but their relationships with local communities. Water use has become a key issue in society and politics, leading to local protests and more stringent environmental permitting. Several mines in our 2018/22 analysis have seen delays to production starts due to difficulties with obtaining water permits or concerns by local communities around water supplies (Tia Maria in Peru, Rosemont in the USA, Rajo Inca in Chile). Above that, water stress in Latin America (c.40% of global supply) has negatively affected production at major mines (Los Pelambres, Los Bronces), resulting in a 10-30% decline in copper production in 1Q22 at affected mines. Therefore, more companies are seeking to diversify water sources and invest in desalination facilities to reduce dependency on weather conditions.

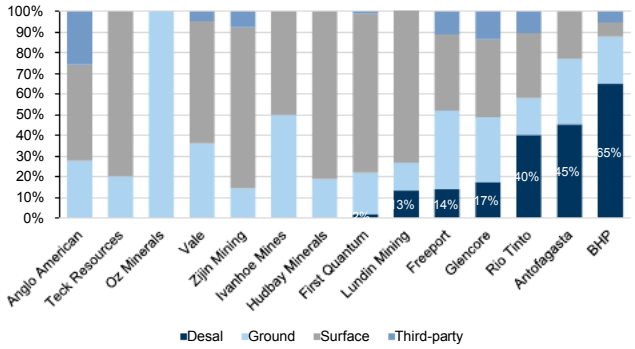
Among our covered companies, we find Rio, Anto and BHP best placed. BHP and Rio Tinto have a 65% and 40% share of sea water in total water withdrawals, respectively. At the start of 2020, the Escondida copper mine (57.5% BHP, 30% Rio Tinto) fully stopped usage of groundwater, and operational water requirements are now 100% supplied via a seawater desalination facility. Antofagasta sources roughly half of its water from the sea, with this share set to rise to >80% after the launch of a desalination plant at the Los Pelambres mine in 2H22. While currently, Anglo American doesn't use seawater in its operations, the company is looking at developing a desalination project in partnership with Codelco to source sea water at the Los Bronces mine. Anglo also aims to eliminate, where possible, fresh water from mining processes as part of its water-less mining strategy by increasing water recycling rates, measuring water evaporation, and studying processing methods such as dry separation; this indicates potential for 30-40% less water use during ore crushing and grinding.

Exhibit 37: Surface and groundwater are the prevailing water sources for global miners
Operational water withdrawal by source, 2021



Source: Company data, Goldman Sachs Global Investment Research

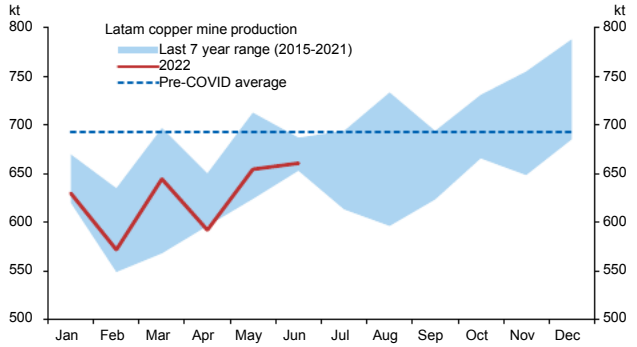
Exhibit 38: Rio, Anto and BHP have the highest share of seawater usage
Operational water withdrawal by source, 2021



Source: Company data, Goldman Sachs Global Investment Research

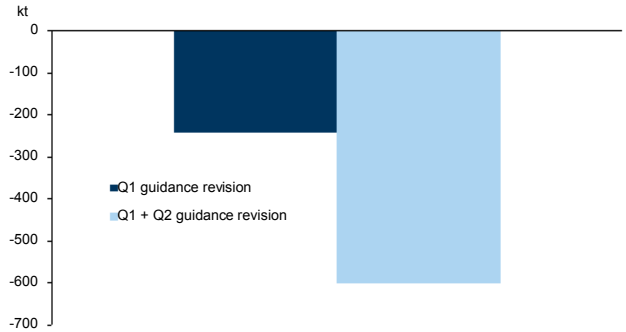
Supply and labor disruptions accelerated in 2022; next wave of labor negotiations in 2023/24 might create additional disruption risks. In 1H22, disruptions to copper concentrate supply equaled c.500kt (c.5% of total global supply in 1H22), slightly above the average run-rate seen over the previous five years. Latin America accounted for c.50% of total disruptions driven by protests, water scarcity, Covid-related absenteeism and labor shortages, and lower milled throughput and ore grades. Mine production in Chile and Peru over 1H22 was at its lowest level since 2017. The largest individual contributions to the shortfall include operations such as Las Bambas (-50 kt), Escondida (-45 kt), Salobo (-37 kt), Los Pelambres (-30 kt) and Cuajone (-25 kt). We saw FY22 production guidance revisions post 1Q and 2Q results for companies in our global coverage (see our reports here and here). While we believe that these effects are transient and production is set to increase in 2H22, we acknowledge that the continued impact of these factors could lead to further downward revisions to production guidance in 2022. While labor-related production losses were minimal in 2020/21, largely reflecting a big wave of renegotiations with labor unions in 2019/20, disruptions caused by labor strikes accelerated in 2022, with labor-related production losses reaching 65 kt in 1H22 vs c.40kt in 2021. The next wave of renegotiations with labor unions in 2023/24 might also create further disruption risks to existing and new mine supply.

Exhibit 39: Continued underperformance in Latam mine production is restricting supply growth
Chile mine production (kt).



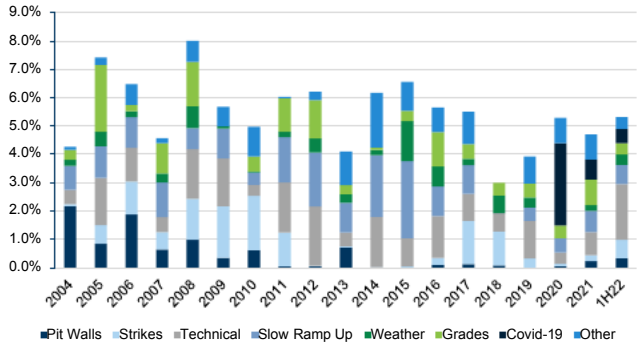
Source: Goldman Sachs Global Investment Research, Haver Analytics

Exhibit 40: Water stress issues and low ore grade have led to continued downward revisions to production guidance
Difference in FY production guidance by GS covered companies (kt).



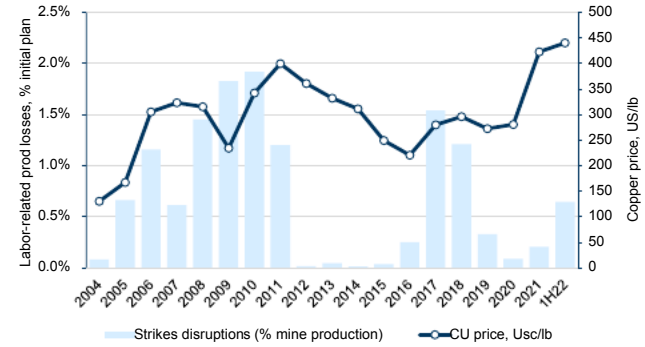
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 41: Supply disruptions decelerated in 2021 on the back of a decreasing COVID impact
Copper supply disruptions



Source: Wood Mackenzie

Exhibit 42: 2020 and 2021 saw very low labor-related disruptions given most labor contracts were renegotiated in 2019 and 2020; the next wave of renegotiations is in 2023/24
Labour disruptions



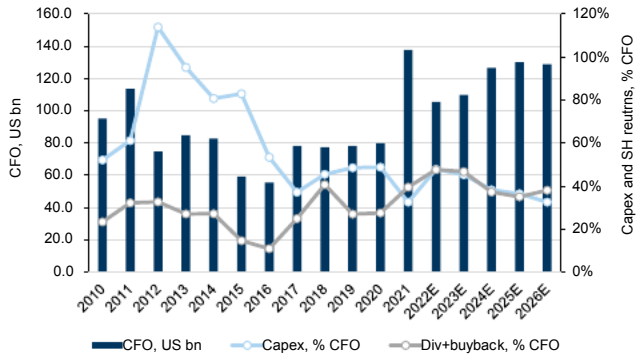
Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Shift from expansion capex to shareholder returns

Despite the rally in copper prices in 2021, we haven't seen mass sanctioning of new projects. We believe this unwillingness to expand production is driven in part by ESG constraints facing miners, alongside a preference for returning shareholder capital; in our Commodities team's view, political-uncertainty-induced risks to the mining sector in Chile in the form of the royalty proposal will likely further hinder new investments (see report here).

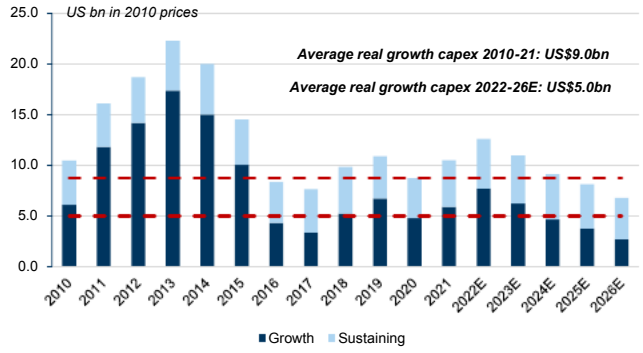
Companies are focused on shareholder returns, growth capex in 2022-26E is 40% less than in the previous decade. Despite the price rally in 2021 and record cash flows, we saw a very moderate capex increase in absolute terms for miners in our global coverage, while the share of CFO directed to capex decreased from 50% in 2020 to 30% in 2021. Even amid the commodity bull cycle, companies are more reluctant to invest further in growth, instead focusing on shareholder returns. Looking at capex at 2010 prices for miners in our global coverage, we expect copper capex on growth projects to average c.US$5bn in 2022-26 compared with a c.US$9 bn average in 2010-21. We expect the share of CFO directed to capex in 2022-26 to be 40% compared with a 65% 10Y average, while we expect shareholder returns (dividends and buyback) to also stand at c.40% of CFO vs a 25% 10Y average. In summary, we find that higher prices do not incentivize higher supply.

Exhibit 43: Despite decade-high cash flows, companies are focused on shareholder returns rather than increasing capex
CFO, capex and shareholder returns for companies in GS's global mining coverage



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 44: Growth capex in real terms is c.40% lower in 2022-26E than in 2010-21
Copper capex in 2010 prices for companies in GS's global mining coverage



Source: Company data, Goldman Sachs Global Investment Research

Top Projects leaders on our supply-side analysis

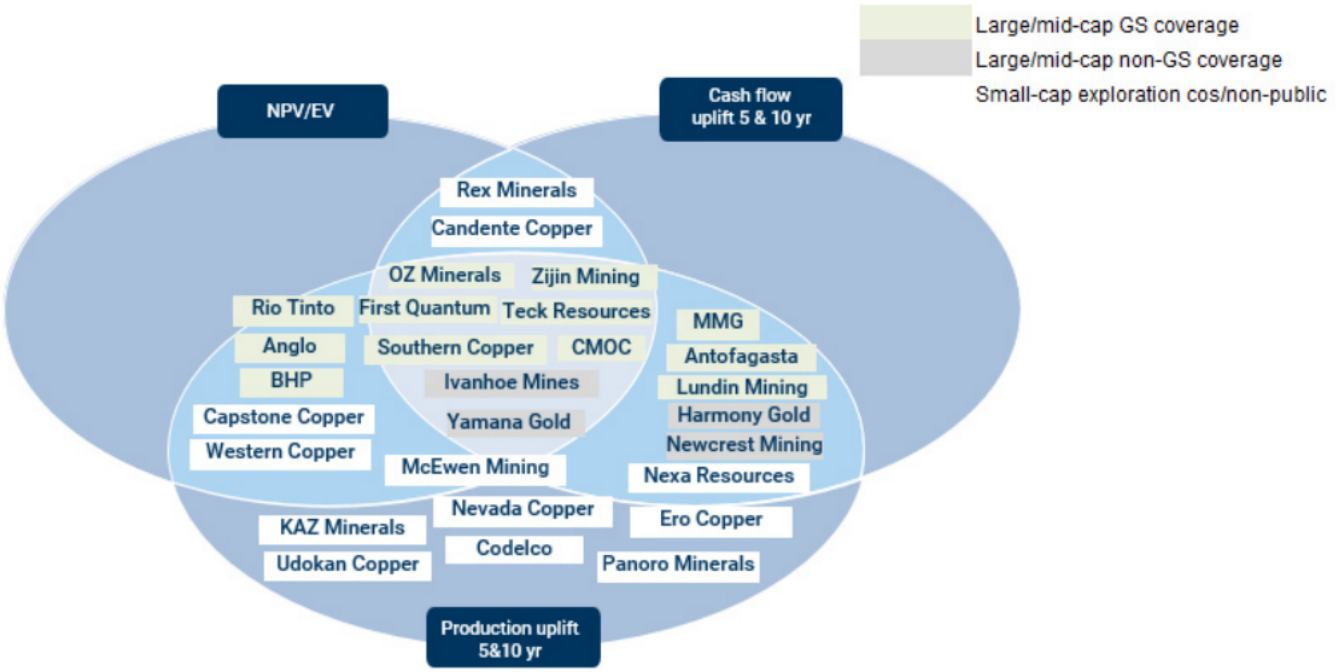
We have identified three groups of project owners that screen well on our analysis of the top-50 copper projects: companies in our global coverage, larger mining companies outside our global coverage, and small-cap exploration and development companies outside our coverage. These companies hold growth projects that are above average on: (1) NPV excl. sunk costs/EV, (2) cash flow uplift in 5/10Y, and (3) production uplift in 5/10Y. Note that this set of metrics reflects the companies' Top Projects portfolio only, and does not take into consideration the rest of their business or their valuation.

In our global coverage, we find that over a 5Y horizon, Zijin Mining, CMOC, First Quantum, Teck Resources, Anglo American and Oz Minerals hold among the strongest growth projects that are highly profitable and could materially lift their future cash flows and production. If we look at **longer-term growth optionality beyond 2026, Southern Copper and BHP** stand out with growth project pipelines that should allow them to offset copper reserve depletion and grade declines. **Rio Tinto, Antofagasta, Lundin Mining and MMG** also benefit from large-scale projects that are likely to substantially increase their production and CFs.

Outside our global coverage, we find that **Ivanhoe Mines and Yamana Gold** screen as holding some of the highest-quality growth assets. Ivanhoe Mines is the operator of the Kamoa-Kakula project, which we expect to grow production by 550kt by 2026; this makes it the highest growth project in our top-50 projects analysis, while it also sits in the most favorable quartile (Q1) of the Top Projects cost curve. Yamana Gold is the operator of MARA project in Argentina which we expect to launch in 2027, with LOM production of c.200kt, with Yamana Gold and Glencore holding 56%/25% in the project, respectively, with attractive economics and incentive price. **Harmony Gold** and **Newcrest Mining** are gold mining companies that have potential to diversify into copper through Wafi-Golpu Project in PNG (LOM production of c.150 kt, 50/50 JV between Harmony Gold and Newcrest Mining).

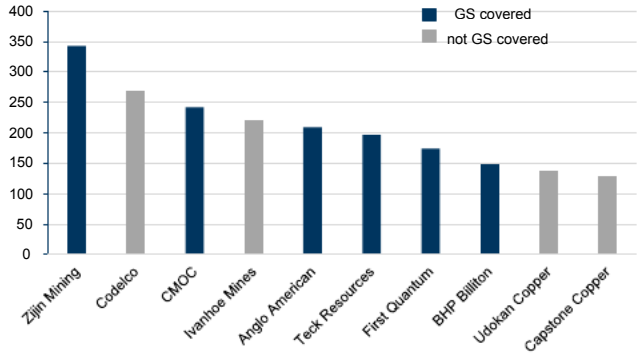
There are also several **small-cap exploration and development companies** that hold high-quality copper growth projects (McEwen Mining, Ero Copper, Rex Minerals, Candente Copper, Panoro Minerals, Nexa Resources, Nevada Copper, Capstone Copper, and Western Copper) that if realized, could provide these companies with cash flow from copper production.

Exhibit 45: In our Top Projects analysis, the below companies hold some of the highest-quality growth assets



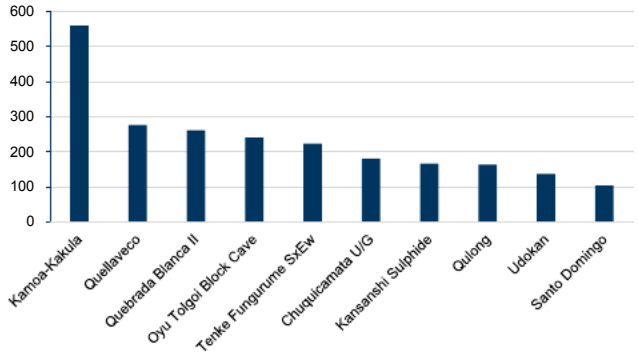
Source: Company data, Goldman Sachs Global Investment Research

Exhibit 46: Zijin Mining, China Moly and Anglo in our global coverage account for the highest volume growth to 2026
Extra copper supply from analyzed copper projects 2021-2026E by company, kt



Source: Company data, Goldman Sachs Global Investment Research

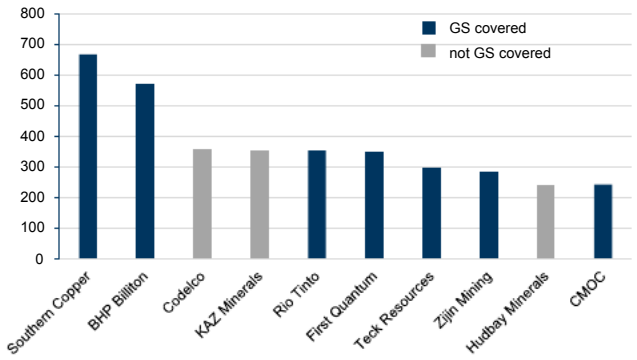
Exhibit 47: Kamoa-Kakula, Quellaveco and QB-2, the 3 largest projects, bring c.1,000 kt by 2026
Extra copper supply, 2021-2026E, kt



Source: Company data, Goldman Sachs Global Investment Research

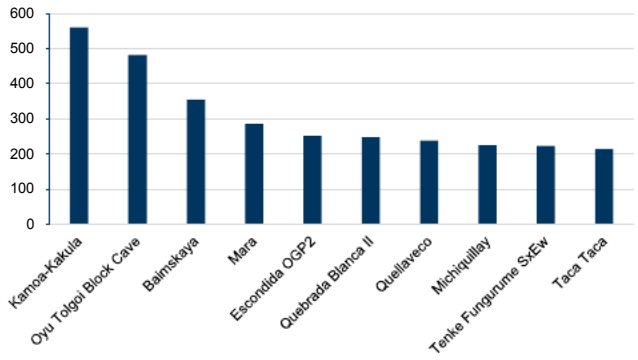
Exhibit 48: Southern Copper, BHP, Rio Tinto and First Quantum hold longer-term cu production projects

Extra copper supply from analyzed copper projects 2021-2030E by company, kt



Source: Company data, Goldman Sachs Global Investment Research

Exhibit 49: Top-10 projects by production growth to 2030E, kt



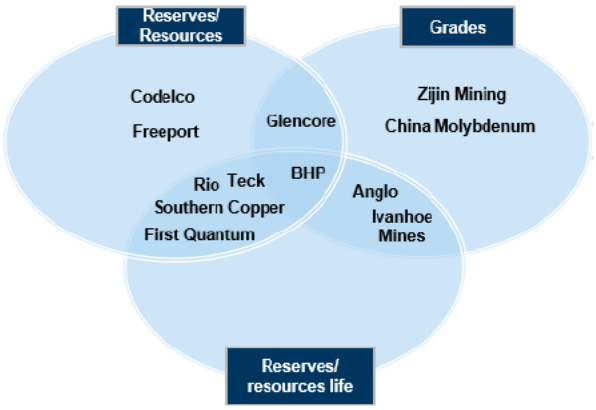
Source: Company data, Goldman Sachs Global Investment Research

Identifying companies with the highest reserves/resource base: BHP, Southern Copper, Ivanhoe Mines stand out

We evaluate the top-50 copper project owners on reserves and resources, grades, contained copper and implied mine lives. We find that:

- Southern Copper, Codelco (Not Covered) and Freeport have the largest copper reserves in the world (contained metal in 2P reserves);
- BHP, Codelco and Rio have the largest copper resources in the world (incl. reserves) given they have significant undeveloped projects;
- Ivanhoe Mines (Not Covered), Southern Copper, Teck Resources and BHP stand out in terms of reserve/resource life; and
- Ivanhoe Mines, Rio, BHP, China Moly and Glencore screen as having the highest reserves/resources grades.

Exhibit 50: The below companies hold some of the highest quality reserves/resources

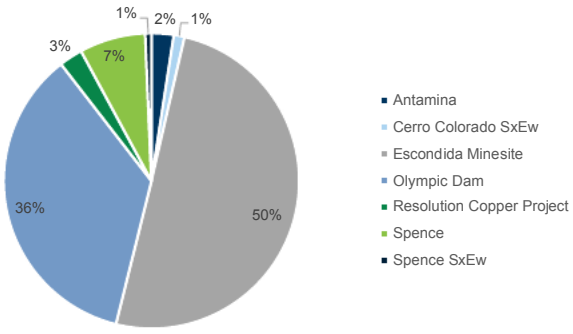


*based on 2020 R&R, and 2021 production

Source: Company data, Goldman Sachs Global Investment Research

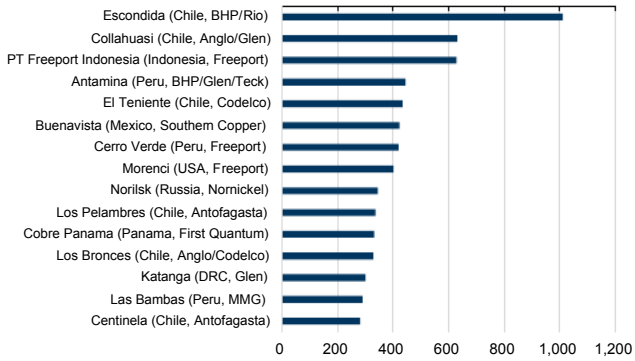
Exhibit 51: BHP screens as an all-round leader given its Escondida operations

BHP Reserves & Resources breakdown, 2020



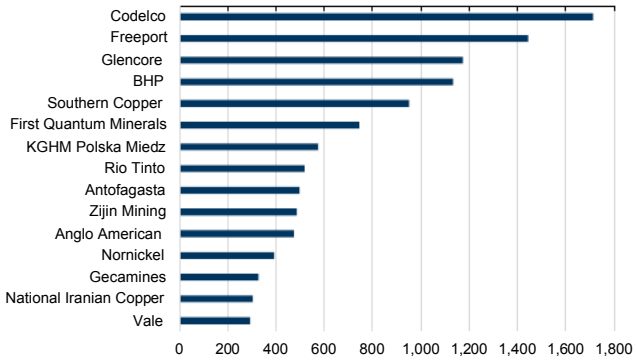
Source: Wood Mackenzie, Company data, Goldman Sachs Global Investment Research

Exhibit 52: Top-15 copper mines by production, 2021



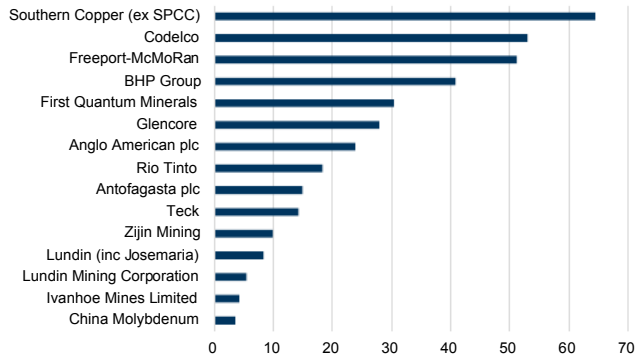
Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 53: Top-15 copper producers, 2021



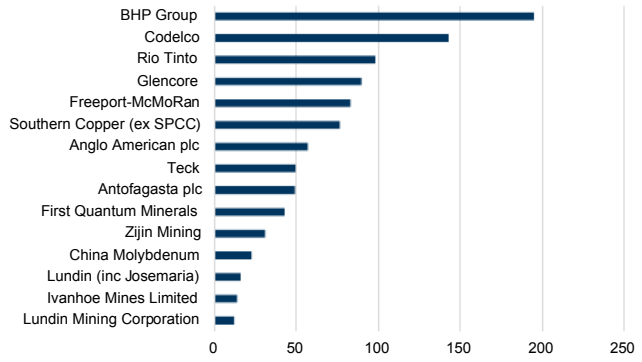
Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 54: Southern Copper, Codelco and Freeport have the largest copper reserves in the world
Copper contained in 2P reserves, 2020



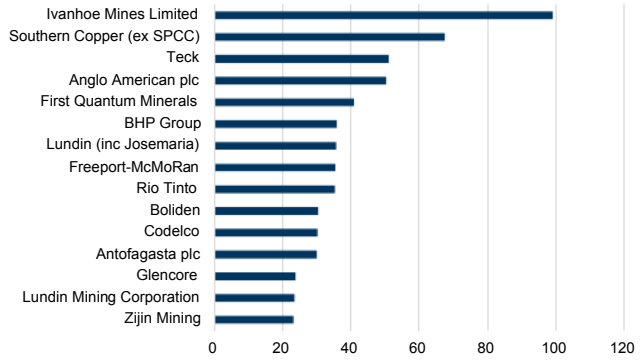
Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 55: BHP, Codelco and Rio have the largest copper resources in the world given they have significant undeveloped projects
Copper contained in M&I resources (incl. reserves), 2020



Source: Wood Mackenzie, Goldman Sachs Global Investment Research

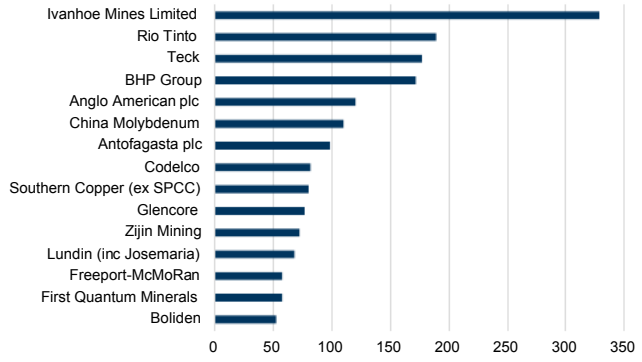
Exhibit 56: Ivanhoe Mines, Southern Copper and Teck Resources have the longest reserve life
2P reserve life, years



2P reserve life is calculated as 2P reserves 2020/Cu production 2021

Source: Wood Mackenzie, Goldman Sachs Global Investment Research

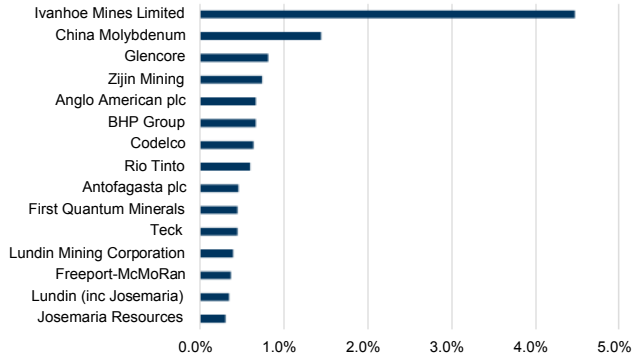
Exhibit 57: Ivanhoe Mines, Rio, Teck Resources and BHP have the longest resource life
M&I resources incl. reserves life, years



Resource life is calculated as M&I resources ex. reserves 2020/Cu production 2021

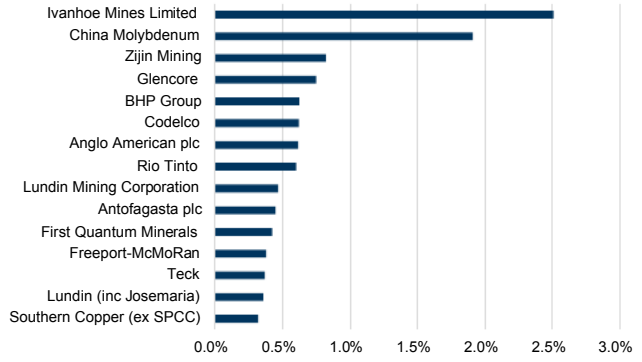
Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 58: Ivanhoe Mines, China Moly and Glen have the highest reserve grades
2P reserves grade 2020, %



Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Exhibit 59: Ivanhoe Mines, China Moly and Zijin Mining have the highest resource grades
M&I resources grade 2020, %



Source: Wood Mackenzie, Goldman Sachs Global Investment Research

Structural demand story intact despite cyclical headwinds

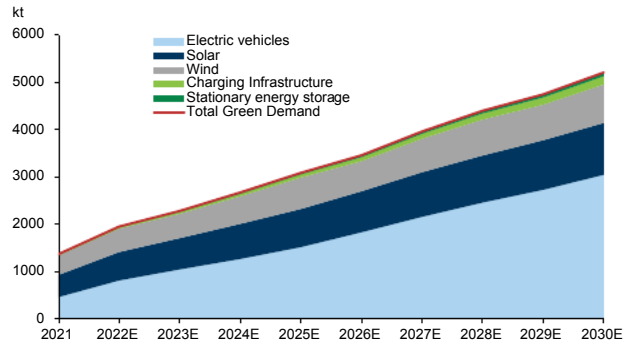
The following chapter outlines the views of our Commodities Research team

Green demand will have an increasing tightening effect throughout the decade, yet as of today it accounts for 4% of global consumption, leaving copper demand exposed to cyclical sector headwinds. Indeed, in the near term, our commodities team retains a cautious view on copper, given deteriorating growth sentiment, mounting recession risk, and sluggish Chinese demand from a weak property sector. They project the copper market to be in a modest deficit in 2022 (119kt), followed by a balanced market in 2023 (GSe 17kt deficit). This reflects lower DM demand projections, as Europe growth faces increasing headwinds from high inflation and reduced gas supplies from Russia, and accelerated mine supply coming online in the next 18 months. However, while China demand has been stagnating until now due to Covid lockdowns, our analysts expect demand to recover into the year-end as infrastructure-focused fiscal stimulus feeds into copper consumption. As such, they forecast prices to move from $7,200/t in 2H2022 to $8,000/t in 1H2023. From 2024, our Commodities team expect the copper market to move back to a tight environment, with open-ended deficits reaching 8Mt by 2030E, twice the size of the gap that triggered the bull market in copper in the early 2000s. On their forecasts, green demand will rapidly increase to account for over 15% of global consumption, matching and then quickly surpassing the incremental demand China generated during the 2000s. On top of strong demand, expected to grow by an average 3.4% in the second half of the decade, our analysts expect supply to start decreasing, after peaking in 2024, reflecting a decade of low investments into new mining projects, a consequence of weak returns and ESG concerns in the mining sector. As a result, our commodities team forecast 2024/25 copper prices at $14,000/t and $15,000/t respectively, with such high levels needed to stimulate a sufficient supply response to match the surge of green demand.

Long-term structural demand story for copper remains intact

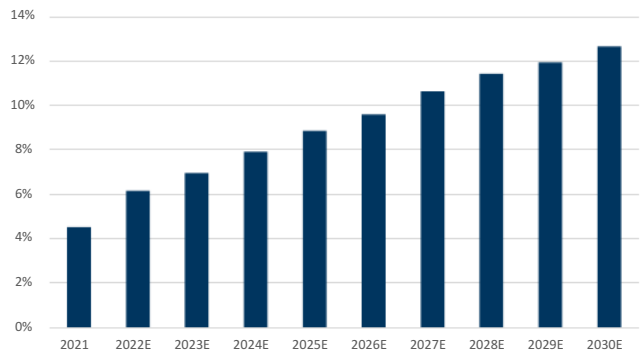
The green transition should support a surge in copper demand. At the core of copper's carbonomics is the need for the world to shift away from a production system based on the chemical energy of hydrocarbons (oil and gas), to one based on a range of sustainable sources – electromagnetic (solar), kinetic (wind) and geothermal. Copper has the necessary physical properties to transform and transmit these sources of energy to their useful final state, such as moving a vehicle or heating a home. Leveraging our equity analysts' carbonomics analysis across EVs, wind, solar, and battery technology, our Commodities team quantifies this demand in a bottom-up model, estimating that by 2030, copper demand from the transition will grow nearly 200% to 5.2Mt. They estimate that by mid decade, this growth in green demand alone will match, and then quickly surpass, the incremental demand China generated during the 2000s. Ripple effects into non-green channels mean the 2020s are expected to be the strongest phase of volume growth in global copper demand in history.

Exhibit 60: A surge in green-related copper demand is expected, from just under 1Mt in 2020 to 5.2Mt in 2030
Copper demand, per year, by green sector



Source: IEA, IRENA, ICA, CDA, Goldman Sachs Global Investment Research

Exhibit 61: Green demand to rise from just 5% of total global demand in 2021 to close to 13% by 2030E
Green copper demand as percentage of total copper demand

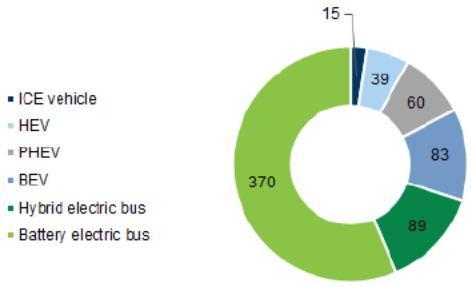


Source: Woodmac, Goldman Sachs Global Investment Research

Electric Vehicles - Surge in adoption to support the most significant green boost to copper demand

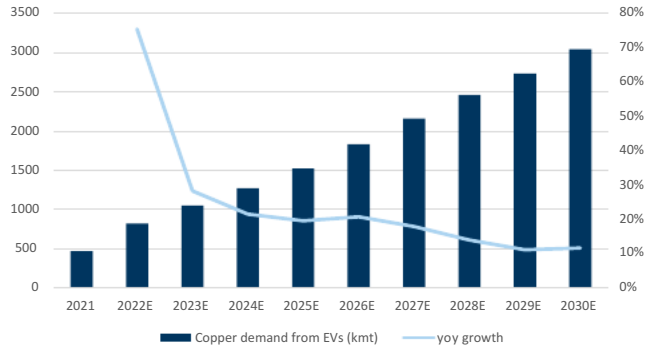
A standard EV's copper content (on average 60-83 kg per car) is four times larger than that of an ICE (on average 15-20 kg per car), with total wiring length of c.1km. Copper is found inside EV batteries, motor coils, inverters and wiring. Our Commodities team estimates 3Mt additional demand from EVs by 2030, driven by increasingly supportive regulation in both Europe and China.

Exhibit 62: Electric vehicles contain substantially more copper than traditional ICEs
Copper content by type of vehicle (kg)



Source: ICA, Goldman Sachs Global Investment Research

Exhibit 63: Our commodities team sees copper demand from EVs growing to c.3Mt by the end of the decade
Copper demand by EVs components

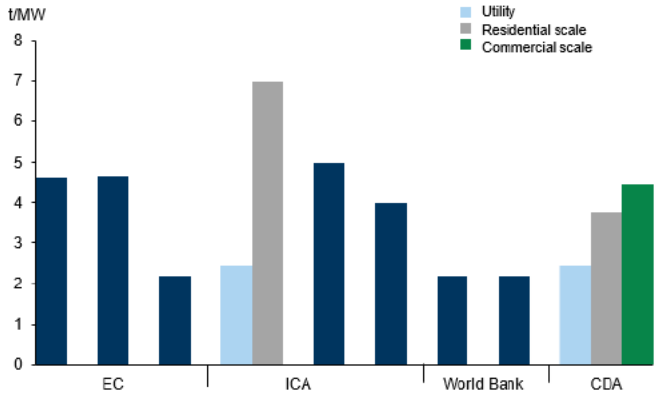


Source: ICA, IEA, Goldman Sachs Global Investment Research

Solar — Sharp acceleration from mid decade, c.500kt in 2021 to 1.1Mt by 2030E

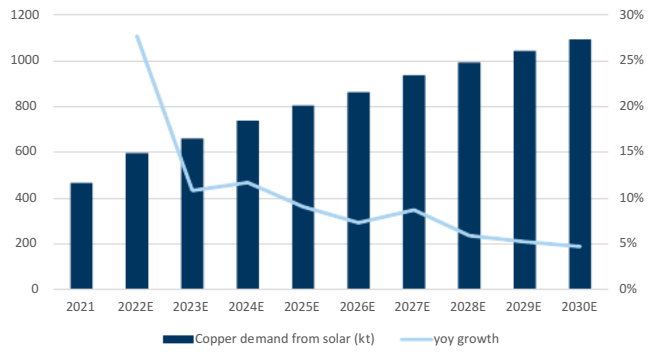
Copper is an essential element in solar PV technologies owing to its high conductivity and cost, giving it a higher conductivity per $/t than silver or gold, critical to maximizing the conversion ratio of photovoltaic to electrical energy. Moreover, its durability is crucial for a technology that has an average life cycle of 25 to 30 years. Over the next decade, our Commodities team sees solar demand rising to 1.1Mt at a rate of c.10% a year.

Exhibit 64: Solar intensities by source and project type
Copper intensity of use in solar PV panels



Source: ICA, European Commission, World Bank, CDA, Goldman Sachs Global Investment Research

Exhibit 65: Copper solar demand to reach 1.1Mt in 2030E
Copper demand coming from solar PV systems

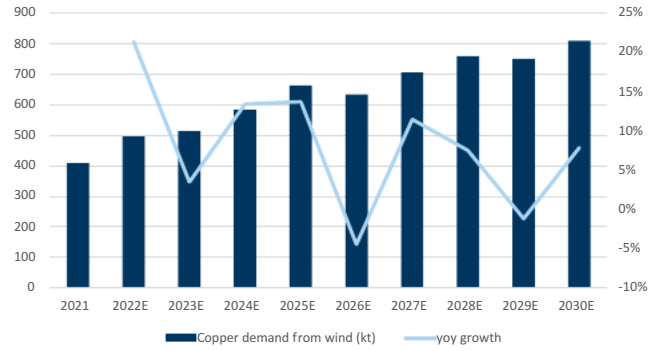


Source: IRENA, ICA, Goldman Sachs Global Investment Research

Wind - Copper demand from turbines set to triple from 400kty currently to 800kt by 2030E

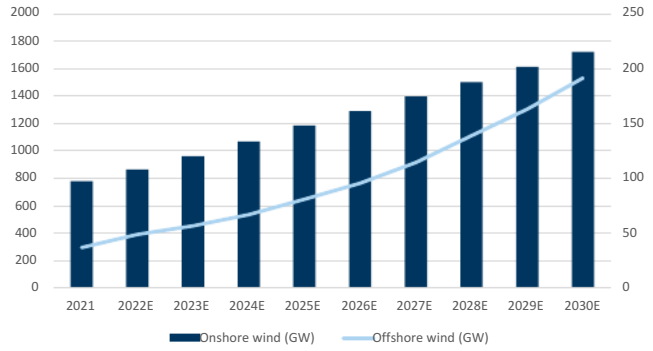
Energy is the largest emitter of carbon globally, accounting for 73% of emissions in 2017. With the electrification of transport and the growing computing demands of AI, energy consumption globally is expected to rise 47% over the next 30 years, according to EIA, requiring a growing renewable energy capacity that will drive wind farm growth in the coming decade. Indeed, our Commodities team sees wind-related copper demand reaching 800kt a year by 2030, growing at a rate of 9% annually.

Exhibit 66: Copper wind demand to reach 1.1Mt in 2030E...



Source: Goldman Sachs Global Investment Research

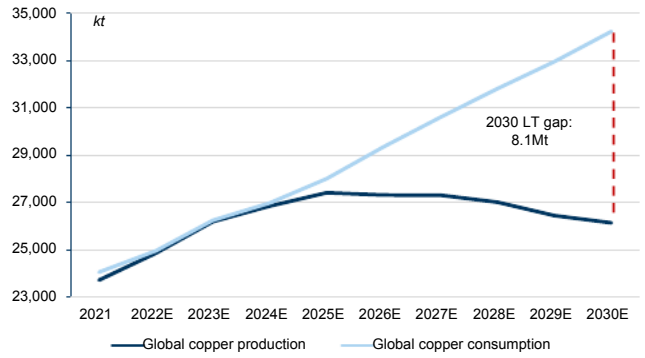
Exhibit 67: ...as wind energy accelerates



Source: Goldman Sachs Global Investment Research

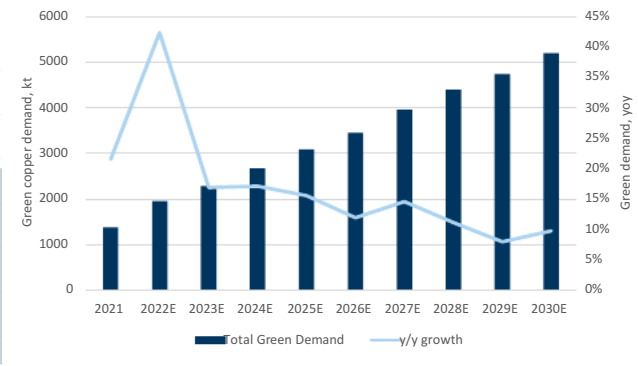
Supply-Demand balance; Largest deficit on record by 2030E

Exhibit 68: Long-term supply gap remains unsolved, with widening mid-term deficits...



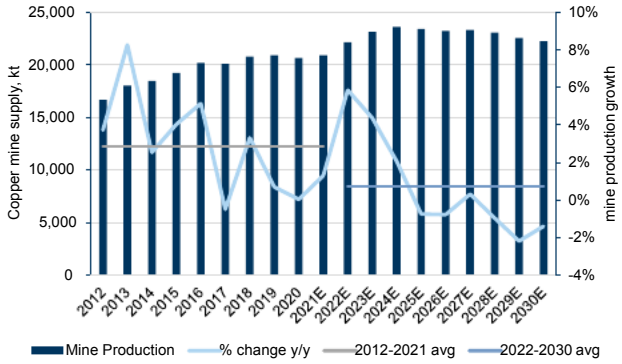
Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 69: ...driven by rising green-related copper demand...



Source: Goldman Sachs Global Investment Research

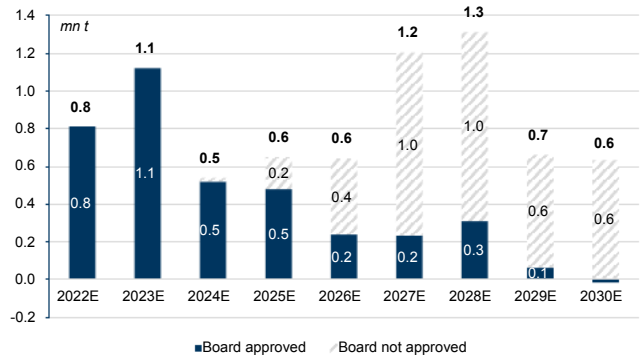
Exhibit 70: ...while mine supply growth falls significantly; c.0.5% mine supply growth in 2022-30E vs a 3% average in 2012-21



Source: Goldman Sachs Global Investment Research

Exhibit 71: c.80% of supply additions in 2027/28E coming from unapproved projects

top-50 projects copper yoy production growth 2022-2030E



Source: Company data, Goldman Sachs Global Investment Research

Appendix

Exhibit 72: GS copper supply-demand balance

('000 tonnes)	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Consumption - DM										
US	2232	2290	2392	2558	2709	2747	2833	2974	3043	3169
% change y/y	*9.0%*	*2.6%*	*4.5%*	*6.9%*	*5.9%*	*1.4%*	*3.1%*	*5.0%*	*2.3%*	*4.1%*
Europe	4995	5271	5433	5773	6097	6421	6789	7091	7330	7577
% change y/y	*7.0%*	*5.5%*	*3.1%*	*6.3%*	*5.6%*	*5.3%*	*5.7%*	*4.5%*	*3.4%*	*3.4%*
Japan	1398	1437	1484	1555	1616	1682	1743	1803	1872	1947
% change y/y	*8.0%*	*2.8%*	*3.3%*	*4.8%*	*3.9%*	*4.1%*	*3.6%*	*3.4%*	*3.8%*	*4.0%*
Other DM	2019	2069	2126	2228	2315	2410	2498	2583	2682	2789
% change y/y	*5.0%*	*2.5%*	*2.8%*	*4.8%*	*3.9%*	*4.1%*	*3.6%*	*3.4%*	*3.8%*	*4.0%*
Sub- DM	10644	11067	11435	12113	12736	13261	13863	14450	14926	15482
% change y/y	*7.2%*	*4.0%*	*3.3%*	*5.9%*	*5.1%*	*4.1%*	*4.5%*	*4.2%*	*3.3%*	*3.7%*
Consumption - EM										
China	14927	15396	16112	16556	16926	17260	17796	18346	18913	19520
% change y/y	*4.7%*	*3.1%*	*4.7%*	*2.8%*	*2.2%*	*2.0%*	*3.1%*	*3.1%*	*3.1%*	*3.2%*
Other EM	4735	4845	5095	5312	5497	5724	5931	6133	6368	6623
% change y/y	*6.0%*	*2.3%*	*5.2%*	*4.3%*	*3.5%*	*4.1%*	*3.6%*	*3.4%*	*3.8%*	*4.0%*
Sub- EM	19662	20241	21208	21869	22424	22984	23728	24479	25281	26143
% change y/y	*4.9%*	*2.9%*	*4.8%*	*3.1%*	*2.5%*	*2.5%*	*3.2%*	*3.2%*	*3.3%*	*3.4%*
Global Consumption	30306	31308	32643	33982	35160	36245	37590	38929	40207	41625
% change y/y	*5.7%*	*3.3%*	*4.3%*	*4.1%*	*3.5%*	*3.1%*	*3.7%*	*3.6%*	*3.3%*	*3.5%*
Direct Global Scrap Use	*5880*	*5903*	*5930*	*6520*	*6669*	*6390*	*6464*	*6580*	*6699*	*6820*
Refined Global Consumption	24046	24951	26240	26970	27999	29347	30601	31803	32946	34223
% change y/y	*2.2%*	*3.8%*	*5.2%*	*2.8%*	*3.8%*	*4.8%*	*4.3%*	*3.9%*	*3.6%*	*3.9%*
Global Production										
Mine Production	20987	22082	23415	24162	24203	23980	24040	23914	23245	22831
% change y/y	*-0.2%*	*5.2%*	*6.0%*	*3.2%*	*0.2%*	*-0.9%*	*0.2%*	*-0.5%*	*-2.8%*	*-1.8%*
Refined Production	23709	24852	26182	26841	27403	27308	27298	27001	26437	26128
% change y/y	*0.4%*	*4.8%*	*5.4%*	*2.5%*	*2.1%*	*-0.3%*	*0.0%*	*-1.1%*	*-2.1%*	*-1.2%*
Global Balance	**-337**	**-100**	**-58**	**-128**	**-596**	**-2039**	**-3303**	**-4802**	**-6508**	**-8094**
Cash Prices (annual average)										
Current Dollars ($/t)	9300	8475	8800	14000	15000	10000	10000	10000	10000	10000
Current Dollars (c/lb)	422	384	399	635	680	454	454	454	454	454

Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 73: EVs and Solar are biggest drivers of green demand
GS global green copper demand model

Global Green Copper Demand Model										
'000 tonnes	2021	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
EU	**345**	**500**	**558**	**653**	**788**	**1029**	**1288**	**1474**	**1601**	**1734**
Solar	61	70	80	115	152	188	223	239	244	244
Wind	117	158	120	108	133	176	272	329	347	373
Stationary energy storage	2	3	4	5	5	6	7	8	9	10
Electric vehicles	160	260	341	407	474	628	747	850	944	1041
Charging infrastructure	6	9	13	18	24	31	39	47	57	67
US	**171**	**198**	**253**	**381**	**517**	**527**	**604**	**729**	**774**	**876**
Solar	63	66	73	82	88	56	56	55	55	54
Wind	55	28	25	69	84	69	35	61	32	58
Stationary energy storage	5	7	9	11	13	15	18	20	23	27
Electric vehicles	46	95	141	213	322	373	478	569	635	701
Charging infrastructure	2	3	4	7	10	13	18	23	29	36
China	**575**	**916**	**1098**	**1275**	**1425**	**1315**	**1390**	**1456**	**1523**	**1621**
Solar	166	251	308	371	436	314	314	314	314	314
Wind	152	205	246	283	308	246	246	246	246	246
Stationary energy storage	2	3	5	8	10	13	17	22	26	31
Electric vehicles	244	441	519	588	640	704	770	825	881	967
Charging infrastructure	10	15	20	26	31	37	43	49	55	62
RoW	**280**	**353**	**385**	**418**	**475**	**588**	**681**	**775**	**893**	**1035**
Solar	176	225	241	259	266	336	376	417	464	514
Wind	86	106	95	91	119	117	129	131	142	165
Stationary energy storage	1	2	3	3	3	4	5	5	6	7
Electric vehicles	15	20	45	62	82	127	164	213	269	335
Charging infrastructure	1	1	2	3	4	5	7	9	11	15
Global green copper demand	**1371**	**1968**	**2295**	**2727**	**3205**	**3459**	**3963**	**4434**	**4791**	**5266**

Source: BNEF, ICA, Goldman Sachs Global Investment Research

Exhibit 74: Chilean taxes under current and proposed systems

New proposed system (producers >200kt)							Spot	1H22
Copper price	US/t	4,408	6,612	8,816	11,020	13,224	8,000	9,700
Copper price	US/lb	2.0	3.0	4.0	5.0	6.0	3.6	4.4
Sales royalty	% price	1.0%	2.0%	3.3%	4.0%	4.5%	2.9%	3.6%
Royalty	US/lb	0.0	0.1	0.1	0.2	0.3	0.1	0.2
Net cash costs (ex.DA)	US/lb	1.5	1.5	1.5	1.5	1.5	1.5	1.5
EBITDA	US/lb	0.5	1.4	2.4	3.3	4.2	2.0	2.7
D&A	US/lb	0.2	0.2	0.2	0.2	0.2	0.2	0.2
EBIT	US/lb	0.3	1.2	2.2	3.1	4.0	1.8	2.5
Profit royalty, % EBITDA	%	2%	11%	19%	28%	36%	16%	22%
Profit royalty	US/lb	0.0	0.2	0.5	0.9	1.5	0.3	0.6
Income tax	%	25%	25%	25%	25%	25%	25%	25%
Income tax	US/lb	0.1	0.3	0.4	0.5	0.6	0.4	0.5
Net income	US/lb	0.2	0.8	1.3	1.6	1.9	1.1	1.4
Total tax take	US/lb	0.1	0.5	1.0	1.7	2.4	0.8	1.3
Aggregate tax take	**% EBITDA**	**20%**	**34%**	**43%**	**50%**	**57%**	**40%**	**46%**
Aggregate tax take	**% EBIT**	**35%**	**39%**	**47%**	**53%**	**60%**	**44%**	**49%**

New proposed system (producers >50kt and <200kt)							Spot	1H22
Copper price	US/t	4,408	6,612	8,816	11,020	13,224	8,000	9,700
Copper price	US/lb	2.0	3.0	4.0	5.0	6.0	3.6	4.4
Sales royalty	% price	1.0%	1.3%	1.5%	1.6%	1.7%	1.4%	1.5%
Royalty	US/lb	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Net cash costs (ex.DA)	US/lb	1.5	1.5	1.5	1.5	1.5	1.5	1.5
EBITDA	US/lb	0.5	1.5	2.4	3.4	4.4	2.1	2.8
D&A	US/lb	0.2	0.2	0.2	0.2	0.2	0.2	0.2
EBIT	US/lb	0.3	1.3	2.2	3.2	4.2	1.9	2.6
Profit royalty, % EBITDA	%	2%	11%	19%	28%	36%	16%	22%
Profit royalty	US/lb	0.0	0.2	0.5	0.9	1.6	0.3	0.6
Income tax	%	25%	25%	25%	25%	25%	25%	25%
Income tax	US/lb	0.1	0.3	0.4	0.6	0.7	0.4	0.5
Net income	US/lb	0.2	0.8	1.3	1.7	2.0	1.2	1.5
Total tax take	US/lb	0.1	0.5	1.0	1.6	2.3	0.8	1.2
Aggregate tax take	**% EBITDA**	**20%**	**32%**	**40%**	**47%**	**53%**	**37%**	**42%**
Aggregate tax take	**% EBIT**	**35%**	**37%**	**43%**	**49%**	**56%**	**41%**	**46%**

Current system (producers >200kt)							Spot	1H22
Copper price	US/t	4,408	6,612	8,816	11,020	13,224	8,000	9,700
Copper price	US/lb	2.0	3.0	4.0	5.0	6.0	3.6	4.4
Sales royalty	% price	0%	0%	0%	0%	0%	0%	0%
Royalty	US/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net cash costs (ex.DA)	US/lb	1.5	1.5	1.5	1.5	1.5	1.5	1.5
D&A	US/lb	0.2	0.2	0.2	0.2	0.2	0.2	0.2
EBIT	US/lb	0.3	1.3	2.3	3.3	4.3	1.9	2.7
EBIT margin	%	15%	43%	58%	66%	72%	53%	61%
Profit royalty, % EBIT	%	5%	7%	9%	11%	12%	8%	10%
Profit royalty	US/lb	0.0	0.1	0.2	0.3	0.5	0.2	0.3
Income tax	%	27%	27%	27%	27%	27%	27%	27%
Income tax	US/lb	0.1	0.3	0.6	0.8	1.0	0.5	0.7
Net income	US/lb	0.2	0.9	1.5	2.2	2.8	1.3	1.8
Total tax take	US/lb	0.1	0.4	0.8	1.1	1.5	0.6	0.9
Aggregate tax take	**% EBITDA**	**18%**	**28%**	**31%**	**33%**	**34%**	**30%**	**32%**
Aggregate tax take	**% EBIT**	**31%**	**32%**	**34%**	**35%**	**35%**	**33%**	**34%**

Current system (producers >50kt and <200kt)							Spot	1H22
Copper price	US/t	4,408	6,612	8,816	11,020	13,224	8,000	9,700
Copper price	US/lb	2.0	3.0	4.0	5.0	6.0	3.6	4.4
Sales royalty	% price	0%	0%	0%	0%	0%	0%	0%
Royalty	US/lb	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net cash costs (ex.DA)	US/lb	1.5	1.5	1.5	1.5	1.5	1.5	1.5
D&A	US/lb	0.2	0.2	0.2	0.2	0.2	0.2	0.2
EBIT	US/lb	0.3	1.3	2.3	3.3	4.3	1.9	2.7
EBIT margin	%	15%	43%	58%	66%	72%	53%	61%
Profit royalty, % EBIT	%	5%	7%	9%	11%	12%	8%	10%
Profit royalty	US/lb	0.0	0.1	0.2	0.3	0.5	0.2	0.3
Income tax	%	27%	27%	27%	27%	27%	27%	27%
Income tax	US/lb	0.1	0.3	0.6	0.8	1.0	0.5	0.7
Net income	US/lb	0.2	0.9	1.5	2.2	2.8	1.3	1.8
Total tax take	US/lb	0.1	0.4	0.8	1.1	1.5	0.6	0.9
Aggregate tax take	**% EBITDA**	**18%**	**28%**	**31%**	**33%**	**34%**	**30%**	**32%**
Aggregate tax take	**% EBIT**	**31%**	**32%**	**34%**	**35%**	**35%**	**33%**	**34%**

Source: Chile Ministry of Finance, Goldman Sachs Global Investment Research

Methodology and assumptions

Below is a summary of how we model each project:

- We model the production profile of each project using the most recent information available. Where applicable, we include specific company guidance on production profiles and otherwise model output according to average LOM production information. Unless otherwise indicated by company guidance, we use reserve/resource details to determine the total mine life of each project.
- Based on disclosed grades, we include all by-product production to compute the Cu equivalent price requirements.
- Revenues of each project are determined using our GS commodities LT price of 10k.
- To compute costs, we assume flat costs at 2021 prices. Unless otherwise specified by companies, we use a 50% split between costs in local currency and USD. Where applicable, we apply our GS forecasts for currencies over 2022-27 — alternatively, rates are set at spot.
- We add estimates for project D&A as well as royalties & taxes depending on the overall life of mine and jurisdiction of each project.
- We follow company guidance on initial capex assumptions and escalate growth capex estimates based on our assumptions. In term of sustaining capex, we model this as a percentage of revenue across all projects (we adjust this percentage where company guidance is available and the overall level of sustaining capex is significantly different from our assumption).
- To discount the cash flows computed, we apply discount rates across projects based on the jurisdiction of each project; note that NPV 2022+ numbers exclude any cash flows incurred before 2022.
- We calculate required rates of returns based on the jurisdiction of each project using USD risk-free rates and USD equity risk premium. For risk-free rates, we use YTMs of long-term government bonds denominated in USD; for equity risk premium, we use a unified 8%, consisting of a standard 5% ERP for mature markets and 3% risk premium for new project development.
- Finally, to compute the required copper price for each project, we set a required IRR based on the jurisdiction of each project.

Copper 101

How is copper produced?

Copper lies beneath the earth's surface embedded in mineral deposits, making it nearly impossible to harvest pure copper directly from the ground. Instead of extracting pure copper, miners extract ore, rock containing metals and minerals. Subsequent processing separates the ore from the metals and minerals. Most of the copper in the world is produced using open pit mines (70% of global mines are open pit). When the ore is too deep, then underground mining is used, which is more expensive and has a higher risk of accidents.

There are two major methods of producing copper: i) pyrometallurgy (flotation), and ii) hydrometallurgy (SX-EW).

Over 80% of the world's copper is made using the flotation process, which results in copper concentrates. The first step in both of the above processes is to mine and extract the ore. Once that is done, the Sulfide ores go through crushing, where they are converted to fine sand, and then mixed with water and chemicals (froth flotation). Air is then passed through the mixture so the copper minerals attach to the air bubbles and float to the surface. This froth on the surface containing copper is then thickened into a concentrate, and then smelted into copper anodes. These are then further refined into copper cathode slabs which are 99.9% copper.

The other method of making copper is through the SX-EW process, which uses oxide ores. The first step, called heap leaching, uses sulfuric acid to separate copper from the ore. The leach is then moved to a solvent to remove impurities, before an electric current is passed through this solvent to positively charge the copper ions, which get plated onto a cathode.

The two main methods used to recover copper minerals from ore are:

Pyrometallurgy uses the following process to produce refined copper.

1. **Mining and milling/concentrating:** After ore is extracted, it is ground to a sand-like consistency. The milled ore is mixed with a frothing solution to remove impurities, producing a concentrate containing 25%-30% pure copper.
2. **Smelting:** The next stage uses heat to break the chemical bonds between copper and other elements in the concentrate, such as iron and sulfur. This process produces 98-99% pure "blister" copper that is cast into shapes to be used as electrical anodes.
3. **Refining:** The copper anodes are immersed in a copper sulfate/sulfuric acid solution. An electric current detaches the copper ions from the anodes and reattaches the ions to prepared thin copper sheets, forming 99.99% pure copper cathodes.

Exhibit 75: Pyrometallurgy

Source: Goldman Sachs Global Investment Research

Hydrometallurgy uses the following process to produce refined copper:

1. **Leaching:** Uses sulfuric acid to dissolve the copper minerals attached to the ore. Dump and heap leaching recover copper from mined ore while in-situ leaching recovers copper from ore within the deposit.
2. **Solvent extraction and electrowinning (SX-EW):** A two-step process used to produce refined copper.
    - Solvent extraction recovers copper ions from a leach solution to produce a copper solvent.
    - Electrowinning uses an electric current to separate the copper ions from the solvent and attaches the copper iron to a series of thin metal sheets. These metal sheets are the 99.99% pure copper cathodes sold to consumers.

Exhibit 76: Hydrometallurgy

Source: Goldman Sachs Global Investment Research

While hydrometallurgy offers lower fixed costs and has a smaller environmental footprint, hydrometallurgy accounts for only about 15% of global copper production because lower recovery rates compared with pyrometallurgy make hydrometallurgy less viable as ore grades decline.

How does SX-EW compare to Flotation?

Advantages

- **Lower fixed costs and capital requirements:** This technology allows small-scale operations to be operated economically. Moreover, the capital investment requirement is lower vs smelting process.
- **Smaller environmental footprint:** SX-EW has a lower environmental impact as its liquid streams can be easily contained. All the impurities are returned to the site of origination, and the sulfuric acid is eventually neutralized by the limestone in the ore body or waste dump where it is deposited as calcium sulfate (gypsum). Water consumption is lower in hydromet operations than conventional grinding and flotation, and energy consumption overall is lower. The avoidance of concentrate smelting also removes the production of sulfurous gases, although modern technology allows for their efficient capture.
- **Ability to recover copper from previously uneconomical sources:** This technology allows the processing and recovering of copper from oxidized ore. This reduces reliance on conventional ore bodies. Moreover, ore bodies with low grades of copper that are not feasible through flotation can be mined through SX-EW.

Drawbacks

- **By-products are not recovered:** The SX-EW process does not allow the recovery of by-products, whereas the flotation method does, and those by-product revenues can be credited against costs.

- **Lower recoveries vs flotation process:** The flotation process has a higher recovery rate than SX-EW, which makes the SX-EW process less viable as ore grades decline.
- **Higher recovery time:** For oxides, recovery time is short, but for other ore bodies, using SX-EW has a much higher recovery time vs the flotation method.

Scope for further improvement in technology could result in significant advantages, including i) access to new ore bodies, and ii) more environmentally friendly mining.

Waste material is dumped because its copper content is too low. However, it can be used in the future if better mining technology enables extraction of such low-grade material. For example, before SX-EW was discovered, all the leachable material was wasted. After 1970, when leaching technology was discovered, material from these dumps was recovered and copper processed from it.

BHP and Freeport are among the companies advancing projects in SX-EW.

BHP — extending sulfide leach operations at Spence & Escondida:

BHP has a US$20bn copper pipeline, which we expect to drive modest production growth and value in the next decade. Those projects, among others, include expanding the sulfide dump leach at Escondida (in GS base case) and converting the dynamic heap leach (in GS base case) and SX-EW plant from oxides to sulfides at the Spence mine:

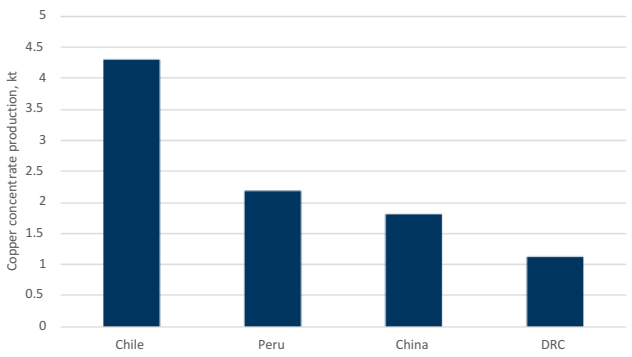
- Converting the Spence SX-EW plant from oxides to sulfides via reprocessing part of the spent ore on the heaps (called ripios); and bacterial leaching of chalcopyrite ore. We think this could extend cathode production by around 100-150ktpa. This is lower than the SX-EW plant nameplate of 180-200ktpa due to the lower grade and leach kinetics (recovery times) of the chalcopyrite ore compared to oxide ore.
- Expanding the sulfide dump leach at Escondida (currently c.220ktpa of cathode on a 100% basis including oxides) and bacterial leaching of chalcopyrite, and implementing the chloride leaching technology recently adopted at Spence. We estimate that this could expand cathode production by c.100ktpa (100% basis).

Freeport - El Abra:

El Abra is a producing copper project located in Chile jointly owned by Freeport (51%) and Codelco (49%). The mine is currently a SX-EW project, but there is a significant sulfide resource which the company estimates at 2 bn tonnes at > 0.45% copper grade. Freeport is currently in the process of advancing technical studies for the project to build a 240kt/d concentrator – similar to the one it built at Cerro Verde. The estimated production, according to the company, could be c.340kt. There have been few details on the mine, particularly relating to capex and cost estimates. Our capex assumption is based on the capex at Cerro Verde. We estimate capex to be c.US$5.3 bn for the project. According to the company, it needs at least 3-4 years for feasibility and permitting, with another 3-4 years needed for construction. Freeport has other projects it is pursuing right now, and as a result we believe that this is unlikely to be at the top of its priority list. Therefore, we expect construction of this project to start in 2026, with first production in 2029 and the mine reaching full capacity by 2032.

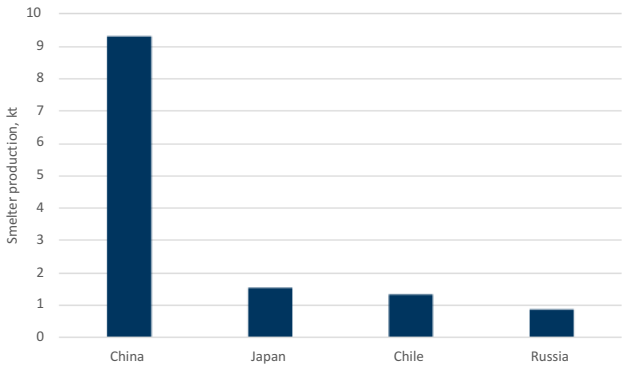
Where is copper produced and smelted?

Exhibit 77: Chile and Peru are the largest copper producers



Source: Wood Mackenzie

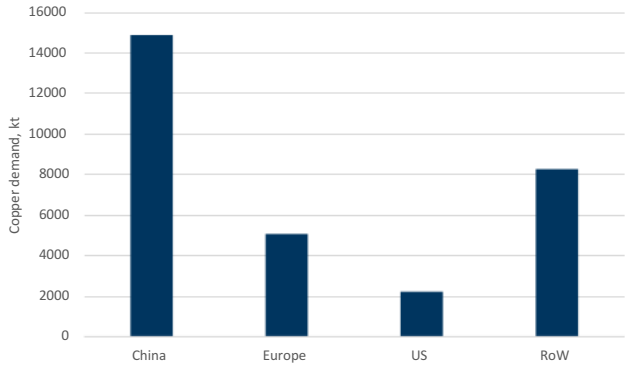
Exhibit 78: China has the largest smelting capacity



Source: Wood Mackenzie

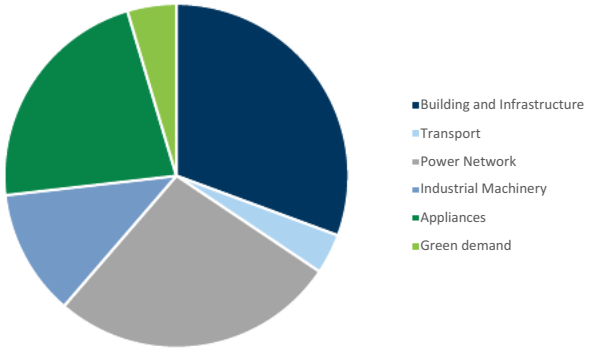
Where is copper consumed?

Exhibit 79: China consumes more than half of the global copper



Source: Wood Mackenzie

Exhibit 80: Global copper demand breakdown, 2021



Source: Goldman Sachs Global Investment Research

Role of scrap copper

Copper scrap is a significant source of copper supply. The reason why scrap plays such a large role in the copper market is that mine supply is highly inelastic in the short run. In contrast to short-cycle commodities like shale oil, where supply can ramp up as fast as within six months, copper mines are known to be long-cycle commodities. Mine supply response can take 5-10 years given that copper mines are capex intensive and complex to construct. In contrast, copper scrap supply responds to price almost immediately as higher prices incentivize scrap dealers to destock. Therefore, copper scrap is essentially a short-cycle commodity and plays a crucial part in reacting to demand fluctuations and balancing the market. Scrap share in smelters and refineries tends to increase when mine supply growth is below trend and decrease when mine supply rebounds. See more here.

Role of copper in decarbonization

In order to understand the central role copper will play in the coming green revolution, it is important to understand how its unique chemical structure gives it a range of useful properties. Copper is a transition metal with a single valence election, giving it the following three properties that make copper the first-best affordable material for use in cables, batteries, transistors and inverters – all key technologies on the path to net zero.

- **Ductility.** Copper is a ductile metal – that is, it can be rolled into sheets and pulled into wires without breaking. When solid, copper is an array of positive ions surrounded by a sea of mobile valence electrons. When a force is applied to the metal, the free-flowing electrons can slip in between the stationary cations and prevent them from coming into contact, shattering the metal. Other elements with a single valence electron – such as silver and gold – have similar properties, but are not available in industrial quantities.
- **Electrical conductivity.** The delocalized electrons in copper are free to move throughout the ion array in 3-dimensions and, crucially, can cross grain boundaries, allowing charge to flow across the metal easily. Moreover, the transfer of electromagnetic energy is strongest when there is little resistance. The most effective conductors of electricity are metals that have a single valence electron that is free to move and causes a strong repelling reaction in other electrons. This is the case in the most conductive metals, such as silver, gold, and copper.
- **Thermal conductivity.** Heat energy is picked up by the electrons as additional kinetic energy is passed along the material. As a result, the best conductors have free electrons that can carry this energy along their length. The energy is transferred throughout the rest of the metal by the moving electrons. Apart from silver, copper is the best.
- **Low reactivity.** Copper is low in the reactivity series, with minimal corrosion of the metal due to a natural protective coating that forms during oxidization – similar to stainless steel. However, stainless steel is substantially less ductile and its thermal conductivity is 30 times worse than that of copper.

Disclosure Appendix

Reg AC

We, Geydar Mamedov, Moomal Irfan, Yulia Bocharnikova, Emily Chieng, CFA, Paul Young, Trina Chen, Joy Zhang, Marcio Farid, Nina Dergunova, Evan Tylenda, CFA, Jojo Kwofie, Devesh Sharma, Hugo Nicolaci, Arthur Deng and Gabriel Simoes, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

We, Nicholas Snowdon, Jeffrey Currie, Aditi Rai and Annalisa Schiavon, hereby certify that all of the views expressed in this report accurately reflect our personal views, which have not been influenced by considerations of the firm's business or client relationships.

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Disclosure

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